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#### FGD WASTE CHARACTERIZATION/DISPOSAL STUDY

Report 87-158-K

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#### ABSTRACT

Based on a review of FGD literature, and from information provided by existing FGD facilities, design and operational problems of "closed loop" operation and associated water balance problems of wet FGD process alternatives have been assessed. Appropriate technology for treatment of FGD process wastewaters to meet environmental regulations has been reviewed. Typical physical and chemical characteristics of potential solid wastes from Ontario Hydro coal-fired stations are described for four candidate FGD processes (Limestone Slurry Scrubber, Dual Alkali, Lime Spray Dryer and Furnace Limestone Injection) based on available information. Results of pertinent waste leachate studies are examined. Solid waste handling options are considered for each FGD system reviewed. It is concluded that, for all four systems there is a need for monitoring and treatment (if necessary) of any leachate from landfilled solid wastes.

| job        | file      | date             | report no. |
|------------|-----------|------------------|------------|
| 31-123-490 | 837.24121 | January 19, 1988 | 87-158-K   |



## ontario hydro research division

### EXECUTIVE SUMMARY

#### FGD WASTE CHARACTERIZATION/DISPOSAL STUDY

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In 1985, as part of the overall federal-provincial program to combat acid rain, the Ontario government tightened its emission limits on acid rain precursors from Ontario Hydro's coal-fired stations. To address one of the various control options available, Ontario Hydro launched an Environmental Assessment program to investigate retrofitting of flue gas desulphurization (FGD) equipment at selected coal-fired stations over a 20-year period. From a review of FGD literature and information supplied by existing FGD facilities, an assessment has been made of design and operational problems of "closed loop" operation and related water balance problems of wet FGD process alternatives. Also, technology for treatment of FGD process wastewaters to meet environmental regulations has been reviewed. Based on available information, typical physical and chemical characteristics of potential solid wastes from Ontario Hydro coal-fired stations are described for four candidate FGD processes (Limestone Slurry Scrubber, Dual Alkali, Lime Spray Dryer, and Limestone Injection). Solid waste handling options are considered for each FGD system reviewed. For all four systems there is a need for monitoring and treatment (if necessary) of any leachate from landfilled solid wastes.



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## ontario hydro research division

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### FGD WASTE CHARACTERIZATION/DISPOSAL STUDY

#### 1.0 INTRODUCTION

In 1985, as part of the overall federal-provincial program to combat acid rain, the Ontario government tightened its emission limits on acid rain precursors (sulphur oxides, nitrogen oxides) from Ontario Hydro's coal-fired stations. To address one of the various control options available, Ontario Hydro launched an Environmental Assessment program to investigate the effects of retrofitting flue gas desulphurization equipment at selected coal-fired stations over a 20-year period. Ontario Hydro plans to install flue gas desulphurization plant at selected thermal generating stations by 1994. For this purpose complete engineering designs have to be ready for submission to the Ontario Government by 1989. An Environmental Assessment (EA) study is currently under way, to be submitted in final form by January, 1988. The work described in this report was carried out to provide a 'state-of-the-art' review of waste characterization/disposal for four processes under consideration. These processes are:

- i) Limestone Slurry Scrubber
- ii) Dual Alkali (limestone regenerant)
- iii) Lime Spray Drying, and
- iv) Limestone Injection into the Furnace (LIF)

Potential sites for these candidate processes are Lakeview TGS, Nanticoke TGS, and Lambton TGS. Of these, Lakeview TGS has no on-site storage space for solid waste. The other two stations have a limited amount of such space, but would eventually have to acquire adjacent property and/or locate off-site landfill disposal areas.

An important aspect of wet FGD processes (especially limestone slurry scrubbing) is the necessity for intermittent discharge of process waste streams, which may arise as a result of several factors. There has been a need for review of appropriate wastewater treatment technologies for reuse or environmentally-acceptable discharge.

## 2.0 LIMESTONE SLURRY SCRUBBER FGD WASTES

A review of FGD literature/1/ has revealed that limestone slurry FGD processing is conventionally carried out under either of two principal variations, ie natural oxidation and forced oxidation. Detailed process flow schemes are given in Appendix A. Disposal area runoff waters may either be recycled back to the plant, or treated at the landfill to environmentally acceptable quality prior to discharge.

### 2.1 Natural Oxidation

Natural oxidation produces an aqueous sludge containing primarily calcium sulphite hemihydrate (major component) and calcium sulphate dihydrate (minor component). The sludge is typically first partially dewatered by thickening/vacuum filtration to ~60% solids, then blended in a pug mill with added lime and fly ash, and the mixture (~80% solids) transported to a landfill site where it is allowed to gradually cure to a hard mass with low aqueous permeability. From a process water standpoint, natural oxidation lends itself to the concept of "closed loop" operation in that the only water losses from the system are (ideally) evaporation via the stack and occluded water in the dewatered scrubber sludge. There is normally no requirement for regular discharge of process water, although water imbalance problems could necessitate occasional blowdown. The occluded water associated with the solid waste contains dissolved species; however, provided that the landfill site is properly designed with a low-permeability liner, leachate migration from the stabilized sludge can be reduced to an insignificant level. This approach to natural oxidation sludge stabilization and disposal has been intensively developed in the USA by Conversion Systems Inc. (CSI) - formerly IUCS - and several other companies including Dravo Inc/2,3/.

### 2.2 Forced Oxidation

Forced oxidation entails injection of air into the scrubber liquor so that the solid waste consists principally of calcium sulphate dihydrate (gypsum) with calcium sulphite hemihydrate as a minor component. Since gypsum crystals have a "blocky" crystalline habit and are easily dewatered, in contrast with the thin platelet/rosette cluster forms of calcium sulfite, the occluded water content of forced oxidation solid waste (~80% solids after dewatering by vacuum filtration) is significantly less than that of the dewatered waste (60% solids) derived from natural oxidation/4/. Under the most favourable conditions, forced oxidation can lend itself to "closed loop" operation, in which the only water leaving the system does so as flue stack-gas evaporation and as occluded water in the solid waste.

The dewatered gypsum waste from forced oxidation FGD, depending on process variation, may either be "dry-stacked" or "wet-stacked"/4,5,6/. Dry-stacking and wet-stacking FGD gypsum processes may each be operated with or without blowdown of process water. In dry-stacking, the dewatered gypsum waste is built up into a graded, bottom-lined and capped mound, and is effectively

protected from infiltration of precipitation, minimizing leaching effects. Wet-stacking of forced oxidation gypsum waste, attractive because of relatively lower waste disposal costs compared to dry-stacking, entails building up a dyked-off suitably lined stack of the solid material by pumping the gypsum as an aqueous slurry (~15% solids) to the top of the stack and allowing it to dewater ("self-filter") to about 80% solids by percolation down through the stack itself. The settled gypsum is periodically excavated by dragline to raise the perimeter dykes of the stack. In general, the stack is divided into two sections, one undergoing excavation while the other receives the gypsum slurry. The aqueous phase that collects around the bottom of the stack is pumped back to the FGD system as recycled scrubber liquor. In very rainy climates, if the efficiency of washing out of chloride from the stack by precipitation is sufficiently high, wet-stacking systems tend to operate at much higher equilibrium chloride concentrations than dry-stacking systems, and require higher blowdown rates to control metal corrosion due to elevated chloride concentrations.

These fundamental variations of FGD limestone slurry processing, ie natural oxidation and forced oxidation, are each capable of operating (ideally) "closed loop". In the case of forced oxidation, however, there is a strong tendency for chloride (present originally in the coal and released into the combustion gases as hydrogen chloride) to accumulate to significant concentrations in the FGD process liquor since relatively little chloride leaves the system as occluded water. Adverse effects of elevated chloride levels in the scrubber aqueous phase are as follows:

- i) Chloride levels above, say, 10,000 mg/L cause serious corrosion problems with most carbon steels/austenitic steels and other common metallic materials of construction, necessitating use of expensive corrosion-resistant high-nickel alloys (either in clad or in solid construction form), or of organic polymeric liners, some of which tend to blister and peel. High capital and maintenance costs are thus associated with scrubbers operating at elevated chloride concentrations.
- ii) Elevated chloride levels in the scrubber liquor tend to lower operating pH to about 5, and reduce sulphur dioxide removal efficiency. The latter may be compensated for by appropriate additions of certain monobasic organic acids (eg formic acid) or dibasic organic acids (eg adipic acid) which are lost mainly by occlusion in the solid waste and require replacement to maintain effective levels.
- iii) In cases where forced oxidation gypsum may be marketed, eg for use as a wallboard component, its commercial usefulness (and value) may be nullified unless appropriate steps are taken to reduce the residual chloride content of the dried gypsum to below industrially specified levels of about 200 mg/kg (for some applications below 80 mg/kg)/4/.

Commercial forced oxidation gypsum manufacture could warrant a discrete filtration/solids-washing stage, discharging the spent chloride-laden wastewater, or else recirculating the wastewater back to the scrubber process loop, with release of a chloride blowdown or purge stream from elsewhere in the loop to achieve a lower system equilibrium chloride concentration. Alternatively, as is common practice in Japan/4/, a prescrubber of expensive chloride-resistant high-alloy construction may be used to remove hydrogen chloride from the flue gas, with blowdown of a chloride-laden purge stream from the prescrubber bottom.

Only about 1% of planned and operational limestone slurry scrubbers in the USA produce commercial gypsum, in contrast with a very much higher percentage in Japan where there is a lack of natural gypsum. Forced oxidation with designed-in blowdown is an effective approach to controlling equilibrium chloride concentrations at predetermined levels/5/, and is applicable to systems with either dry-stacking or wet-stacking of gypsum.

In summary, limestone slurry FGD scrubber systems fall into 7 broad categories (with numerous sub-variations and features) as follows:

1. Natural oxidation with sludge fixation
2. Forced oxidation without blowdown (dry-stacking)
3. Forced oxidation without blowdown (wet-stacking)
4. Forced oxidation with blowdown (dry-stacking)
5. Forced oxidation with blowdown (wet-stacking)
6. Forced oxidation with blowdown (commercial gypsum - gypsum wash)
7. Forced oxidation with blowdown (commercial gypsum - prescrubber)

Details of these alternatives are given in Appendix A/4,5/.

The design equilibrium chloride level to be used is selected to minimize corrosion effects on the materials of construction while maintaining an acceptably high sulphur dioxide removal efficiency. Even FGD systems with expensive high-alloy construction may require intermittent blowdown, to handle water balance problems that may arise from time to time.

### 2.3 Limestone Slurry FGD Systems - Water Balance

For a given limestone scrubbing system, there is a water balance to be maintained. It is basic scrubber design practice to aim for the fresh water makeup requirement for a "closed loop" system to satisfy the combined needs for:

- i) reagent preparation
- ii) demister wash water and
- iii) pump seal water

Ideally, a "closed loop" scrubber system operating at steady state, full load conditions will operate with a well-controlled water balance. However, should the load decrease significantly, pump seals deteriorate, or valves leak on the demister wash header, problems can result, necessitating an "unscheduled" system blowdown. For an open loop limestone scrubber system, which operates at a designed blowdown rate with a predetermined equilibrium chloride concentration, water balance problems can result in increased system blowdown rates. Likewise, forced oxidation FGD scrubbers which utilize wet-stacking are vulnerable to water imbalances should precipitation rates exceed design levels. As will be described below, the increased blowdown volumes should be taken care of by application of appropriate wastewater management/control procedures introduced at the design stage/7/. Recent experience with mechanical pump seals and revised mist eliminator washing strategies/8,9/ indicate progress in maintaining a closed water loop balance by reducing water influx to the system in these areas. The implication is that the challenge in closing the water loop may become one of process chemistry rather than of water balance.

In terms of solute chemistry, the foregoing discussion has been limited mainly to consideration of chloride concentrations in FGD scrubber liquors. From a process standpoint this is indeed highly appropriate, since chloride levels affect process efficiency for sulphur dioxide removal, as well as capital and operating costs. FGD scrubber wastewaters generally contain a wide range of species of concern besides chloride, many of which, eg calcium sulfate, have limited solubility and can cause scaling, while others, though minor components, are nevertheless of environmental concern. It is generally assumed that chlorine originally present in the coal is released almost entirely to the combustion flue gases as highly-soluble hydrogen chloride, which is virtually completely absorbed into the scrubber liquor. Other coal components released during combustion include a broad spectrum of major, minor and trace species, the preponderant mass of which is removed as fly ash in the electrostatic precipitators. Combustion gases exiting the precipitators contain fine particulate material (post-precipitator fly ash) and a number of volatilized species. Certain components of these may be absorbed into the scrubber liquor, and ultimately may be released into the aqueous environment (a) by blowdown discharge, (b) by occlusion in the aqueous phase of the scrubber sludge/solid waste, or (c) as leachate from dry or wet solid waste stacks. Depending on the efficacy of site-specific provisions for discharge, these species may contaminate local surface waters and/or ground waters. The need for treatment of these aqueous streams depends on locally applicable wastewater discharge criteria. It should be noted that presently in the USA, FGD solid wastes are exempt from EPA hazardous waste categorization under the Resources Conservation and Recovery Act (RCRA). However, aqueous discharges are subject to control under Federal, state and local legislation. It is expected that similar Federal and Provincial regulatory considerations would apply to a wet limestone scrubber system installed in Ontario, Canada.

Although coal and electrostatic precipitator fly ash are generally analyzed for a given FGD installation, it should be noted that it is usually the post-precipitator fly ash that contributes to trace element composition of unstabilized forced oxidation scrubber liquor and hence of blowdown/leachate streams where applicable. (In the case of natural oxidation fixated sludge, to which regular fly ash is added prior to landfill disposal, the fly ash components may be leachable - though the fixation process should minimize this in principle). Very few utilities analyze their post-precipitator fly ash, however, making it very difficult to predict aqueous concentrations of trace metals, especially for forced oxidation, in scrubber waste streams.

## 2.4 Engineering Considerations for Landfill Sites

Detailed design of FGD limestone scrubber waste disposal operations is site and system specific. Several wet limestone scrubbing process options have previously been described. However, some broad engineering considerations are important in defining environmental impact issues/3,4,6/.

### 2.4.1 Physical Stability

Physical instability is a potential problem for all wet limestone scrubber wastes, including stabilized and fixated wastes (see below). Geometric factors such as height and slope angle in a waste disposal site are interrelated; stability depends on the combination of fill height, slope angle, waste density, degree of saturation, effective cohesion, effective angle of shearing resistance, and behaviour during shearing. For a given material, safe fill height decreases with increasing slope angle. For proper design, data are required in which maximum safe fill height is related to slope angle and soil shearing behavior. Such relationships have not been thoroughly developed yet for FGD wastes mainly because of inadequate data from proper tests (eg, triaxial compression tests on consolidated samples with measurement of pore water pressures).

Instability of a waste deposit can develop due to inherent or incipient weakness of the underlying strata (a "basal failure" in geotechnical terminology).

Erosion of cover materials could be important. If a relatively low permeability cover soil or seal layer were removed through erosion, and if relatively pervious waste were exposed by this erosion, infiltration of precipitation or surface runoff into the waste deposit could increase. This could lead to saturation of previously unsaturated waste, resulting in significant porewater pressures. Saturation would increase the weight of the waste, and porewater pressure generation would decrease the strength of the waste deposit. These combined factors tend to cause sliding/slumping. In any case, erosion of cover materials depends on a combination of particle sizes, particle shape and interparticulate cohesion.

#### 2.4.2 Compaction

Instability problems may be ameliorated by compaction, since compaction may produce several changes, eg, voids may be eliminated, waste density may be increased, and particles moved closer together may be bonded more effectively in fixation reactions. If the original waste resembles sandy soil, an increase in density during compaction may create an important increase in angle of shearing resistance. Compressibility would also be decreased by an increase in density.

The behaviour stability of settled calcium sulphite wastes under compaction equipment will vary with the solids content of the wastes (assuming no fixation of the wastes), and probably with the type of compaction equipment (static, rubber-tired, steel roller, vibratory, etc). For example, experience at the Scholz plant, in Florida indicated that it was necessary to dewater waste to 70-75% solids content before compaction could be accomplished. Sulphite wastes tested to date may be incapable of supporting compaction equipment of any kind unless such high solids contents are first achieved. 'Liquefaction' may be an even more serious threat in calcium sulphate wastes, especially under vibratory loading. Field tests are required to investigate this question on a case-by-case basis.

#### 2.4.3 Climate

Climate can affect the stability of an FGD waste deposit in several ways. The total amount of rainfall and the intensity of rainfall tend to increase the rate of surface erosion. As mentioned above, infiltration of water into FGD waste deposits can lead to saturation, decrease in apparent strength, and, possibly, to failure. This would be most likely to occur with wastes of high permeability in an unsaturated condition, but it could occur in any improperly designed wet limestone scrubber FGD waste deposit.

Freeze-thaw cycles could have several effects. Stabilization and fixation could be retarded, disrupted or destroyed by an episode of freezing soon after mixing and placement. Freezing could produce cracks in the near-surface layers of a waste deposit. Cracks in the waste deposit could yield greater mass permeability and infiltration rate. In a fill created in layers over a number of years, freeze-thaw effects on temporarily exposed faces and surfaces could produce horizontal layers through the finished deposit, with high "crack" permeability in such layers. Increased permeability could lead to increased formation of leachate. On the other hand, freeze-thaw cycles may be effective at some sites in dewatering surface layers. The problems of crack formation could be ameliorated by compaction of the thawed material after maximum possible evaporative dewatering and before placement of additional waste. Freeze-thaw effects clearly require case-by-case investigation.

#### 2.4.4 System Design and Post-Closure Land Use

Often it is difficult to specify the ultimate use of the land on which FGD waste disposal is planned. However, it is important to recognize engineering constraints on post-closure land use. For example, placement of an earth material cover in a uniform layer over the entire waste deposit should be feasible. But imposition of concentrated loads (eg, footings in a building) may cause bearing failure with rapid plunging of the loaded element into the waste. Vibratory loads, eg, from machinery foundations, could have disastrous effects on unfixated wastes. The rate of application of load is also extremely important - loads applied slowly may allow consolidated of the wastes during loading, yielding higher strength than for material loaded rapidly. Rapid application of load increases shearing stresses and may decrease shearing resistance if the structure of the wastes is disturbed.

Uses of adjacent land could be restricted by access limitations (eg, difficulty in building access roads across FGD waste deposits), or by pollution effects (losing the use of local groundwater through pollution by leachate from FGD wastes).

In choosing a given site for FGD waste disposal, all technical, economic and environmental factors should be considered. Obviously, waste land areas with irregular topography (for ease of containment and a source of cover soil) and highly impervious subsoils would be ideal. Valuable, flat or uniformly sloping areas with highly pervious soils and scarce, pure ground water would be poor locations for disposal sites. Wetland would be a poor choice.

#### 2.4.5 Runoff-Related Considerations

To limit water losses by runoff from an FGD waste deposit, grading and drainage during construction should be employed as in any other construction activity. After completion of the deposit, a cover soil is chosen to limit infiltration. A soil consisting of a mixture of clay, silt and sand fractions is better for this purpose than a material of uniform grain size, irrespective of the average grain size.

To limit formation and egress of leachate, water infiltration into the fill can be minimized by the techniques mentioned above. The water content of the FGD waste is minimized by dewatering prior to placement and a seal layer is prepared in the bottom of the fill area. A pervious drainage channel could be constructed to surround the waste deposit to collect leachate and carry it to a central sump. From the sump, the leachate could be recycled to the scrubber (if feasible), or it could be sprayed on the surface of the fill to utilize evaporation as a means of reducing leachate quantity. It could also be piped to a treatment plant if necessary. Should the natural subsoils at the disposal site be very pervious, a seal layer may be required below the drainage channel.

#### 2.4.5.1 Design of Landfill

Landfill design can be based on many configurations. Three broad generic configurations are:

- a) Heaped Landfill: This is the structurally simplest form of landfill which may be utilized with level terrain. Even though this design is simplest in terms of site preparation and may offer advantages in terms of slope stability and groundwater pollution, it is often aesthetically undesirable.
- b) Side Hill Landfill: This is advantageous and often utilized in areas of hilly terrain where the natural slope of one side of a hill or valley may provide containment. The side hill landfill must be prepared properly to ensure stability.
- c) Valley Landfill: This is the most common type of landfill used, and is often the most complex in terms of original site preparation. Natural valleys or ravines are often sources of surface water runoff and may have springs along side slopes. In such cases, surface water and groundwater control is usually necessary to avoid accumulation of water and the development of a leachate problem. Drainage must be provided and, in some cases, hydrologic modifications are necessary to divert water flow around the landfill.

Design of a managed FGD waste landfill requires adequate data on the engineering properties of the waste and of the soils at the site. Laboratory tests should include determination of shear strength, unconfined compressive strength and permeability. A proper design is necessarily site specific. Good landfill design requires control of both leachate movement and runoff. Stabilization and fixation processes improve handling/disposal of the waste.

Stabilization of an FGD waste typically entails addition of fly ash, which has the effect of reducing water/moisture content of the waste, while giving it improved handling characteristics and physical cohesion.

Fixation of an FGD waste frequently entails addition of lime, which permits formation of an inorganic, chemically cross-linked cementitious structure, containing complex calcium aluminosilicates, with significantly reduced permeability and increased strength.

#### 2.5 Prediction Of Wet Limestone FGD Waste Water/Leachate Characteristics

From a knowledge of ultimate coal analysis, and for a given limestone scrubber design variation, it is possible to calculate the design "closed loop" and open loop equilibrium process liquor concentration of chloride/5/. This is based on a few reasonable assumptions - eg that 95% of the Cl in coal is volatilized as HCl and that 95% of the HCl is absorbed in the scrubber liquid

as chloride. The chloride concentration in the water occluded in the solid waste leaving the scrubber can thus be calculated, as can the blowdown rate, where applicable. As for other species present in scrubber wastewater, calcium sulphate, calcium sulphite and calcium fluoride levels can be calculated from solubility limitations. Concentrations of minor and trace elements in scrubber blowdown are much more difficult to predict, however. Individual species originally present in the coal burned will eventually be distributed among many phases, including the bottom ash, electrostatic precipitator fly ash, post-precipitator fly ash, stack gas particulate and volatile phases (eg Hg, Cd, As, Zn), scrubber sludge solids, and scrubber sludge liquid (aqueous) phase. This is further confounded by speciation and solubility considerations related to such parameters as pH, redox potential and other complex interacting variables.

Leachate composition is difficult to predict a priori and depends on sludge-related factors including limestone reagent type and purity, proportion of fly ash present, water quality and extent of oxidation. It is also time-variable. Radian Corporation/3/ have developed laboratory batch shake and column leaching tests to try and obtain meaningful data, though projection of the results to actual disposal conditions is difficult. Leachate quantity is also difficult to predict and depends on permeability of sludge and underlying soil, climatic effects (eg, rainfall), and site specific design and management practices (eg, sludge stabilization, use of liners, etc).

## 2.6 Environmental Objectives for Wastewater Discharges

A summary of environmental objectives related to waste water discharges in North America is given in Table I, which compares relevant Provincial water quality criteria in Ontario with those of Environment Canada and United States Federal standards/1/.

## 2.7 Technologies for Wastewater Treatment and Reuse

To achieve "closed process water loop or equivalent", proposed in the Design Phase Environmental Code of Practice developed by Environment Canada/10/, there are a number of alternative approaches to treatment of blowdown wastewater streams to maintain a water balance, or to prevent process chemistry-related problems such as corrosion or scaling.

Available technologies that have been considered include:

1. Mechanical Evaporation (in particular Vapour Compression Evaporation)
2. Reverse Osmosis, and
3. Electrodialysis

These are considered in turn below, as well as strategies for reuse of purified wastewaters.

Table 1  
ENVIRONMENTAL OBJECTIVES RELATED TO WASTEWATER DISCHARGES  
IN NORTH AMERICA

|                            | Environment Canada<br>Codes of Practice<br>(1) | Ontario MOE<br>Discharge Criteria<br>(3) | Ontario MOE<br>Surface Water<br>Quality Objectives<br>(16) | Ontario MOE<br>Drinking Water<br>Objectives<br>(17) | US EPA<br>NPDES<br>(3) | US EPA<br>NIPDWS<br>(3,18) | US EPA<br>NSDWR<br>(3) |
|----------------------------|------------------------------------------------|------------------------------------------|------------------------------------------------------------|-----------------------------------------------------|------------------------|----------------------------|------------------------|
| pH                         | 6.5 - 9.5                                      | 5.5 - 9.5                                | 6.5 - 8.5                                                  | -                                                   | 6-9                    | -                          | 6.5-8.5                |
| Alkalinity                 | -                                              | -                                        | <1.25 x background                                         | -                                                   | -                      | -                          | -                      |
| SO <sub>4</sub>            | -                                              | minimize (BAT)                           | -                                                          | 500                                                 | -                      | -                          | (250)                  |
| Cl                         | -                                              | minimize (BAT)                           | -                                                          | 250                                                 | -                      | -                          | (250)                  |
| NO <sub>3</sub> (as N)     | -                                              | -                                        | -                                                          | 10.0                                                | -                      | -                          | -                      |
| Ag                         | -                                              | -                                        | <0.0001                                                    | 0.05                                                | -                      | -                          | -                      |
| Al                         | -                                              | -                                        | undefined                                                  | -                                                   | -                      | -                          | -                      |
| As                         | -                                              | -                                        | <0.1                                                       | 0.05                                                | -                      | 0.05                       | -                      |
| B                          | -                                              | -                                        | undefined                                                  | 5.0                                                 | -                      | -                          | -                      |
| Be                         | -                                              | -                                        | <0.11                                                      | -                                                   | -                      | -                          | -                      |
| Ba                         | -                                              | -                                        | undefined                                                  | 1.0                                                 | -                      | 1.0                        | -                      |
| Cd                         | -                                              | 0.001                                    | <0.0002                                                    | 0.005                                               | -                      | 0.01                       | -                      |
| Cr                         | 0.5                                            | 1.0                                      | <0.1                                                       | 0.05                                                | -                      | 0.05                       | -                      |
| Cr (VI)                    | 0.05                                           | -                                        | -                                                          | -                                                   | -                      | -                          | -                      |
| Cu                         | 0.5                                            | 1.0                                      | <0.005                                                     | 1.0                                                 | -                      | -                          | 1.0                    |
| Fe                         | 1.0                                            | -                                        | <0.3                                                       | 0.3                                                 | 1.0                    | -                          | 0.3                    |
| Hg                         | -                                              | 0.001                                    | <0.0002                                                    | 0.001                                               | -                      | 0.002                      | -                      |
| F                          | -                                              | -                                        | -                                                          | 2.4                                                 | -                      | 1.4-2.4                    | -                      |
| Mn                         | -                                              | -                                        | undefined                                                  | 0.05                                                | -                      | -                          | 0.05                   |
| Mo                         | -                                              | -                                        | undefined                                                  | -                                                   | -                      | -                          | -                      |
| Ni                         | 0.5                                            | 1.0                                      | <0.025                                                     | -                                                   | -                      | -                          | -                      |
| Pb                         | -                                              | 1.0                                      | <0.025                                                     | 0.05                                                | -                      | 0.05                       | -                      |
| Se                         | -                                              | -                                        | <0.1                                                       | 0.01                                                | -                      | 0.01                       | -                      |
| Sn                         | -                                              | 1.0                                      | -                                                          | -                                                   | -                      | -                          | -                      |
| U                          | -                                              | -                                        | -                                                          | 0.02                                                | -                      | -                          | -                      |
| V                          | -                                              | -                                        | undefined                                                  | -                                                   | -                      | -                          | -                      |
| Zn                         | 0.5                                            | 1.0                                      | <0.03                                                      | 5.0                                                 | -                      | -                          | 5.0                    |
| TDS                        | -                                              | minimize (BAT)                           | <1.33 x background                                         | 500                                                 | -                      | -                          | (500)                  |
| TSS                        | 25                                             | add <15 mg/L                             | -                                                          | -                                                   | 100                    | -                          | -                      |
| Oil & Grease               | 15                                             | 15                                       | -                                                          | -                                                   | 20                     | -                          | -                      |
| Total Residual<br>Chlorine | 0.2                                            | -                                        | -                                                          | -                                                   | -                      | -                          | -                      |
| Phenols                    | -                                              | 0.02                                     | -                                                          | 0.002                                               | -                      | -                          | -                      |
| BOD (5-day)                | -                                              | 15                                       | -                                                          | -                                                   | -                      | -                          | -                      |

All concentrations given in mg/L

NPDES denotes US EPA National Pollutant Discharge Emission Standards

NIPDWS denotes US EPA National Interim Primary Drinking Water Standards

NSDWR denotes US EPA National Secondary Drinking Water Regulations (bracketed figures proposed)

BAT denotes best available technology

### 2.7.1 Mechanical Evaporation

In 1985, Canviro Consultants Ltd. of Kitchener, Ontario, submitted a detailed report/11/ entitled "An Evaluation of Flue Gas Desulphurization Wastewater Treatment by Mechanical Evaporation" to the Environmental Protection Service of Environment Canada. The report assessed the technical feasibility of applying mechanical evaporation as a treatment technology for FGD wastewaters, as well as the attendant environmental implications for full-scale implementation in Canada. The report contains a review of the relevant technical literature, supported by contact with equipment suppliers. Of special note, Resources Conservation Co., of Washington State, have developed antifouling 'seeded' slurry vapour compression evaporators, and are leaders in this field. Pilot scale evaporation tests/11/ were carried out by Resources Conservation Co. in cooperation with Canviro on wastewaters from three US FGD scrubber systems to characterize the condensates and concentrates. Laboratory tests were also conducted by Canviro to further define the fate of specific contaminants during FGD wastewater evaporation.

Although over twenty full-scale mechanical evaporators were reported to be currently in use at coal-fired power stations in the US, these units all treat cooling tower blowdown and/or miscellaneous plant wastewaters. There is very little experience related exclusively to mechanical evaporation of FGD wastewaters. Mechanical evaporators in use are invariably of the falling film, vertical tube design. Problems of scaling, plugging and corrosion encountered with this equipment can be overcome by proper design of demisters and flood box distributors. Careful materials selection (to counteract chloride/fluoride corrosion) and "seeded" slurry operation (to prevent scaling by calcium sulphate, calcium carbonate etc) can be advantageous. Canviro predicted that the technology of mechanical evaporation of FGD wastewaters should be technically feasible, but noted that insufficient technical information has been reported to predict product water quality. Canviro conducted pilot-scale evaporation tests on limestone slurry FGD scrubber wastewater samples collected from three US coal-fired power stations:

- i) Southwest Power Station, Springfield City Utilities, Springfield, Missouri (Natural oxidation, operating with dibasic acid (DBA) addition to improve SO<sub>2</sub> removal efficiency)
- ii) Seminole Power Station, Seminole Electric Corporation, Palatka, Florida (Forced oxidation design but newly commissioned - operating as a "closed loop" natural oxidation system) and
- iii) Dallman Station (Unit 3), Springfield Water, Light and Power, Springfield, Illinois (Forced oxidation, designed "closed loop" but needs intermittent blowdown to overcome water balance problems; gypsum disposal practised)

These US stations were selected on the basis of satisfying the maximum number of criteria relevant to generation of wastewaters expected to be generated from Canadian wet limestone slurry scrubber FGD operation at coal-fired stations. Preferred site selection criteria included:

- i) Stations with limestone slurry FGD scrubbing, ideally in the forced oxidation mode,
- ii) Stations burning medium sulphur coal (2-3.5%) with a chloride content of over 0.1%,
- iii) Stations operating as close as possible to "closed loop", and generating a high TDS wastewater,
- iv) One station (at least) to be using an organic acid (DBA/adipic acid) to improve SO<sub>2</sub> removal efficiency and
- v) One station (at least) to be producing by-product gypsum.

Coal characteristics of the selected stations are given in Table II.

#### 2.7.1.1 Pilot-Scale Tests

The pilot-scale evaporation tests attained concentration factors ranging from 6 to 30, yielding brines containing 17 to 42% TDS. Product waters derived from the Southwest Power Station and the Seminole Power Station FGD wastewaters were of very high quality (5 and 12 mg/L TDS respectively). Product water from the Dallman Station wastewater contained 70 mg/L TDS; boron was the main component present.

In the pilot-scale studies, boron and organics accumulated in the product waters to a much greater relative extent than non-volatiles (such as chloride). Mercury and selenium were partially volatilized from the evaporator sump, and, based on poor mass recoveries in the pilot tests, it was concluded that they may have been lost from the system as non-condensibles. Arsenic levels in these wastewaters were too low to draw conclusions.

#### 2.7.1.2 Laboratory-Scale Tests

Carefully controlled laboratory tests were conducted using Dallman Station wastewaters, spiked with additions of arsenic, mercury, selenium, iron, nickel and zinc. Mercury was found to be more volatile than selenium. Arsenic was relatively non-volatile. Significantly, it was also found that laboratory-scale tests had limited value in predicting quality of condensate from a larger-scale evaporator treating the same feed.

Table II

COAL CHARACTERISTICS OF STATIONS SELECTED FOR PILOT-PLANT  
MECHANICAL EVAPORATION OF FGD WASTEWATERS/11/

| Unit, Station<br>Utility             | Unit No. 1<br>(194 MW)<br>Southwest Power<br>Station.<br>Springfield City<br>Utilities | Units Nos. 1&2<br>(2x650 MW)<br>Seminole Power<br>Station.<br>Seminole Electric<br>Corp. | Unit No. 3<br>(192 MW)<br>Dallman Station.<br>Springfield Water,<br>Light & Power |
|--------------------------------------|----------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Coal, Type,<br>Origin                | Bituminous,<br>S.E. Kansas                                                             | Bituminous,<br>W. Kentucky                                                               | Sub-bituminous,<br>Illinois                                                       |
| Average Heat<br>Value, (MJ/kg)       | 29.1                                                                                   | 31.4                                                                                     | 24.1                                                                              |
| Average Ash<br>Content (%)           | 15                                                                                     | 9.4                                                                                      | 10.6                                                                              |
| Average<br>Moisture Con-<br>tent (%) | 10                                                                                     | 6.5                                                                                      | 18.0                                                                              |
| Sulphur Con-<br>tent (%)             | 2.5 - 4.5                                                                              | 2.9                                                                                      | 3.4                                                                               |
| Chlorine Con-<br>tent (%)            | 0.3                                                                                    | 0.22                                                                                     | 0.10 - 0.15                                                                       |
| Cl/S ratio                           | 0.12 - 0.07                                                                            | 0.08                                                                                     | 0.03 - 0.04                                                                       |

#### 2.7.1.3 Technical/Environmental Implications

Although the Canviro technical review indicates mechanical evaporation to be a feasible technical approach to FGD wastewater treatment (with proper design), the lack of reported long term operating experience and the short duration of the pilot plant studies precluded identification of long-term operational problems.

The condensates generated by mechanical evaporation of FGD wastewater from each station were generally of better quality than the supply of fresh service water, and reuse as boiler feed makeup water is considered to be widely practicable. Boron and organics evaporated to the condensate could conceivably be removed by a suitable condensate polishing system if

required. Discharge of the condensate to the receiving water would be environmentally acceptable, though wasteful of a potential source of high quality raw water.

The concentrates from mechanical evaporation contain high concentrations of inorganic salts. This waste stream could (at least partly) be used for fly ash wetting for fugitive dust control; however, it would probably be deleterious to supplies of otherwise saleable ash. Disposal as stabilized landfill via fixation with alkaline fly ash and lime may also be practicable, though this is speculative.

Environment Canada's proposed criteria<sup>10/</sup> for wastewaters discharged from thermal generating stations include pH, suspended solids, chromium, copper, iron, nickel and zinc. All of the criteria were found to be met by the pilot-scale evaporation test condensates from the three stations investigated, except for a slightly low pH from the Southwest Station, requiring neutralization prior to discharge. Boron and selenium, while not directly addressed in Environment Canada's proposed criteria, are the only components found in any of the condensates that might be cause for concern in discharging to receiving waters.

Canviro Ltd. recommended, based on the results of their investigation of mechanical evaporators and the findings of the parallel study by CH2M Hill /5/, that an integrated water/waste management system be developed for Canadian power stations.

#### 2.7.2 Reverse Osmosis

Recently, growing interest has been expressed in examining the feasibility and cost-effectiveness of reverse osmosis (RO) as a pollution control/water reclamation process for treatment of FGD blowdown streams and other power station wastewaters for reuse or discharge<sup>5,12,13,14/</sup>. RO is a pressure-driven membrane separation technique whereby a wastewater is pumped under pressure (typically 2.1 to 6.9 MPa) through a chamber lined with a suitably-supported semi-permeable membrane, commonly made of a cellulose acetate or polyamide material. Purified water (permeate) passes through the membrane for collection and reuse as appropriate, while dissolved species (contaminants) are retained on the high-pressure side of the membrane as a relatively low-volume concentrate, which has to be disposed of. The rate of flux of purified water through the membrane is proportional to the difference between the applied pressure and the opposing solution osmotic pressure of the waste stream being concentrated. The degree of conversion of feed stream to product water is limited by the concentration (and osmotic pressure) of the concentrate ultimately produced. Available commercial membranes are imperfect barriers to solutes, and a certain amount (typically much less than 10%) of dissolved species pass through with the product water. For

some feebly ionized hydrogen bonding solutes, eg boric acid in neutral or acidic solution, passage is significantly higher (50-60%). Commercial RO membrane module equipment is available in three principal design configurations: tubular, spiral wound, and hollow fibre/15/. In wastewater treatment, spiral wound and (especially) hollow fibre membrane modules tend to foul and plug much more easily than tubular units. This is due to deposition of suspended solids or precipitation of sparingly-soluble species on the concentrate side of the membrane. A variant of conventional RO, termed "seeded" RO, is now being offered by at least one vendor of tubular RO equipment (Resources Conservation Co., of Washington State). This utilizes the principle that in presence of a sufficiently large amount of "seed crystals", scale-forming salts precipitate preferentially on the suspended "seed crystals" rather than depositing as a foulant on the membrane walls. Golomb/14/ has demonstrated pilot-scale applicability of self-induced "seeded" RO to treatment of fly ash leachate, which tends to reach  $\text{CaSO}_4$  saturation or even supersaturation during RO concentration. All of this suggests that some form of "seeded" RO may be applicable to treatment of gypsum-laden FGD wastewaters. It is predictable that low concentrations of barium in FGD wastewaters can form practically insoluble barium sulphate, which could, in principle, cause severe RO membrane fouling problems. However, fouling by barium sulphate was not observed to occur during self-induced "seeded" RO of fly ash leachate/14/, and may not be a significant problem for "seeded" RO treatment of FGD wastewaters either.

For power plant wastewater discharges to date, application of "seeded" RO has been limited to laboratory pilot-scale testing, eg treatment of cooling tower blowdown/5/. While "seeded" RO has the advantage of requiring less pretreatment compared with conventional RO, certain commonly-shared limitations are predictable, eg the inability to operate effectively with the high TDS/chloride concentrations (and high osmotic pressures) associated with many FGD blowdown streams. For FGD systems operating with organic dibasic acids, there is also the possibility of organic fouling of membranes. Furthermore, the temperatures of FGD blowdown are typically in the range of about 50-55°C, ie at or above the recommended maximum operating temperature (50°C) for most RO membranes; this would necessitate precooling of the FGD waste stream. Finally, even though many of the pretreatment stages (and costs) associated with removal of scaling salts for conventional RO may be avoided, the low membrane surface area per unit volume associated with tubular membranes for "seeded" RO is expected to result in a significantly higher equipment capital cost than for conventional RO. As indicated above, another limitation of RO is that it is restricted to treatment of relatively dilute solutions compared with mechanical evaporation.

### 2.7.3 Electrodialysis

Electrodialysis (ED), an electrically-driven membrane separation technique for water purification has seen relatively little commercial application in treatment of industrial wastewaters. The most common application of ED to date has been in desalination of brackish water (< 8,000 mg/L TDS) for

potable use. The water to be purified is pumped between stacked membranes, which are alternately cation-permeable or anion-permeable. In presence of an applied electric field, generated by an anode and cathode positioned at opposite ends of the stack, migration of anions and cations takes place, forming alternately solute-rich (concentrated) and solute-depleted (purified) streams between the membranes. These streams are continuously withdrawn as a concentrated brine and a product water. As far as FGD blowdown treatment is concerned, ED membranes have a higher operating temperature limit (65°C) compared with RO membranes (50°C). The membranes are, however, susceptible to fouling by organics and scaling by sparingly-soluble salts associated eg with calcium hardness. This would necessitate pre-treatment, as for conventional RO. Silica, being feebly ionized, is not effectively removed by ED, which limits reuse of the product water for boiler feed purposes. Whereas RO is not well suited to treatment of high-TDS FGD wastewaters because of poor permeate recoveries, ED is limited instead by high processing costs. ED power consumption is related directly to the amount of TDS to be removed. Economics dictate that ED is not to be used above about 5,000 mg/L of TDS, which renders it unsuitable for high-TDS FGD blowdown treatment/5/.

#### 2.7.4 Freezing

The freezing of a salt solution causes crystals of pure water to nucleate and grow, leaving a brine concentrate as the mother liquor. Pure water is obtained by separating and melting the ice formed. Despite attempts at commercialization, freezing is presently considered to be a developing process for water desalting, mainly limited to pilot-scale seawater desalination. Nevertheless, the process has also been tested on a pilot-scale with limited success in the power industry for treatment of cooling tower blowdown/5/.

#### 2.7.5 Comparison of Alternative Wastewater Treatment Methods

Depending on the particular wet scrubbing FGD process variation selected, and the materials of construction used, it may be either feasible or impractical to operate without a process liquor purge. In any event, a "closed loop" FGD system must be capable of operating at practically zero discharge, ie reusing any blowdown generated either within the FGD process, or elsewhere in the station water system. The potential of treatment for reuse of FGD blowdown is limited by high TDS and especially high chloride concentrations. Of the various advanced treatment processes available for TDS removal from FGD purge streams, only vapour compression evaporation (VCE) has been applied with any appreciable success to date, mainly limited to pilot-scale tests. VCE presents fewer operational limitations compared with membrane processes (RO, ED) and is technologically much more advanced than freezing processes at this time.

#### 2.7.6 Reuse Strategies For Renovated Wastewaters

It has been found/5,7,11/ that, at least in principle, treated FGD wastewater can be used, perhaps after an appropriate degree of further purification, in various power station areas of application, including the following:

- a) as a supplement or replacement for FGD process makeup water, ash transport water, or general plant service water and/or,
- b) reuse as boiler makeup after polishing to remove trace elements carried over with the condensate.

Of these options, reuse as boiler makeup/11/ offers the greatest economy, since the purity of condensate from mechanical evaporation will generally be close to that of boiler makeup water which is normally prepared at considerable expense by ion exchange treatment of raw water supplies. Steam-volatile species that may be present in condensate from vapour compression evaporation include traces of boron, organics, and (in some cases) selenium. Major ions normally expected to be present in the distillate in low, but measureable concentrations include calcium, sodium, potassium, chloride and sulphate, all of which are present at high concentrations in the FGD blowdown evaporator feed/concentrate stream.

Conventional strong base anion/strong acid cation resin ion exchange demineralization should be capable of removing the trace major ions cited as well as boron and selenium (as borate and selenate), provided organic concentrations are low enough to have insignificant potential for fouling of the strong base anion resins. Otherwise, an upstream organic trap ion exchanger may have to be installed, using salt-regenerated strong-base anion resin/5,11/.

It should also be noted that, since anion resins have an operational temperature limitation of  $\sim 50^{\circ}\text{C}$ , cooling of evaporator product water by additional heat exchangers may be necessary. Projected capital and operating costs of distillate treatment for limestone FGD scrubbers in Ontario and Nova Scotia, with reference to alternative forced oxidation/blowdown processes and with certain assumptions, have been estimated by CH2M Hill/5/. Annual average revenue requirements were predicted to vary widely, according to FGD variation and discount rate applied (6-15%), between 0.09 and 0.64 mills/kWh.

It should nevertheless be borne in mind that most US utilities practising limestone slurry FGD scrubbing with blowdown evaporation have integrated wastewater treatment systems to optimize reuse of wastewater on a station-wide basis. The technology (and economics) required to meet discharge water criteria are site-specific.

#### 2.8 Summary & Conclusions

A feature common to all of the limestone slurry FGD variations, especially forced oxidation, is the potential need for continuous or intermittent blowdown of process liquor to control chloride concentrations. High levels

of chloride have an adverse effect on SO<sub>2</sub> removal efficiency, and can lead to corrosion problems. There is a shortage of long-term operating data for treatment systems (especially mechanical evaporation) for process liquor blowdown. Landfill of the solid wastes should be accompanied by monitoring and, where necessary, treatment of leachate to meet environmentally acceptable ground and surface water quality criteria.

### 3.0 DUAL ALKALI FGD WASTES

#### 3.1 Dual Alkali - Conventional Lime Regeneration

In the dual alkali FGD process, the makeup reagent for SO<sub>2</sub> absorption is typically soda ash. A recirculating aqueous solution of sodium bisulphite NaHSO<sub>3</sub> (in equilibrium with Na<sub>2</sub>SO<sub>3</sub>, NaOH, Na<sub>2</sub>CO<sub>3</sub>, and NaHCO<sub>3</sub>) acts as the principal reagent for SO<sub>2</sub> removal in the dual alkali system, whereas any dissolved sulphate (formed by natural oxidation in the absorber by flue gas oxygen) reduces the capacity for SO<sub>2</sub> removal. Excessive sulphate formation could even necessitate a purge. Regeneration of the spent absorber liquid is usually accomplished by addition of lime or (far less frequently to date) by less expensive limestone. This precipitates the major waste product calcium sulphite hemihydrate (CaSO<sub>3</sub>·1/2 H<sub>2</sub>O) and, as minor waste component, calcium sulphate dihydrate (CaSO<sub>4</sub>·2H<sub>2</sub>O). In practice, co-precipitation of these two solids has been observed/16/. Typical dual alkali regenerant sludge contains/17/ a SO<sub>3</sub><sup>=</sup> to SO<sub>4</sub><sup>=</sup> molar ratio of at least 4 to 1.

The most significant operating problem/16/ has been control of the regeneration reactions to form large waste solid crystals that simultaneously facilitate slurry dewatering and dissolved sodium reagent recovery for economic recycle back to the absorber. Presence of magnesium (originating in the regenerant lime/limestone, for instance) can lead to precipitation of magnesium hydroxide at elevated pH, blinding the vacuum filter cloth.

Despite the apparent simplicity of the process, dewatering and disposal of the sulphite sludges pose problems that merit further research and development, of which the chief goals are:

- i) to recover the sodium values present in the sludge as efficiently as possible for economic reasons (especially reagent conservation), and
- ii) to reduce as far as possible the soluble sodium salt content in the interstitial pore water of the fixated, stabilized, final disposal site wastes, to minimize leaching and possible physical weakening of the landfill structure.

In general, dual alkali wastes are thixotropic and resemble wet limestone natural oxidation slurry scrubbing wastes in their handling/disposal characteristics, except that they may contain residual sodium salts as a

result of incomplete removal at the vacuum filter cake washing stage. Dual alkali scrubbers operate "closed loop" to the maximum extent feasible to conserve sodium reagent values.

In the USA, the solid dewatered sludge (consolidation strength 7.6 MPa/17/) can be landfilled "as is", sometimes after stabilization with fly ash.

A sample of lime-regenerated dual alkali sludge filter-cake was obtained from the R.M. Schahfer Station 17 & 18, Indiana, USA, together with a sample of the corresponding landfill stabilized filter cake. Each material was subjected to the Ontario MOE Leachate Extraction Procedure/33/. It was found (Tables III and IV) that the materials were non-"leachate toxic", and essentially acceptable for landfill use in the Province of Ontario.

In analogous fashion, lime-regenerated dual alkali sludge filter-cake and Poz-o-tec (IUCS/CSI) landfill material were obtained from Newton Station 1, Illinois, USA, where there had been reports of use of limestone for regeneration (Limestone use has since been discontinued for economic reasons). Again, the materials were found to be non-"leachate toxic" and acceptable for landfill in Ontario, when subjected to the MOE Leachate Extraction Procedure/33/ (Tables V and VI).

### 3.2 Dual Alkali - Limestone Regeneration

It is widely recognized that limestone has a cost advantage over lime for acid neutralization in industry. However, use of limestone rather than lime as regenerant was claimed/16/ in 1983 to have the disadvantage of lower dissolution rate. It has also been claimed that use of limestone adversely affects solids dewatering characteristics.

With conventional lime regenerated dual alkali FGD, dissolved sulphite (ie, as sodium bisulphite) is the primary agent for SO<sub>2</sub> removal. Regeneration of the spent absorber liquid can be technically accomplished using limestone instead of lime. In 1980 to 1981 such a study/18/ was funded by EPRI at the Gulf Power Company's Scholtz Plant, in conjunction with an EPA process demonstration of a 20 MW scale limestone dual alkali scrubber. The waste treatment and disposal program study was curtailed to about four weeks because of budgetary constraints and yielded only 70 Mg of stabilized sludge. No field leachate monitoring was performed; a laboratory testing program was implemented instead. The laboratory analyses showed that:

- 1) One of the lime/fly ash stabilized laboratory mixtures studied was suitable for landfill if compacted with light machinery. This sample had a solids content of 56%, a fly ash-to-filter cake ratio of 1:1, a 3% lime content and a natural water content below its liquid limit.
- 11) The shear strength of the stabilized sludges increased with greater stabilization (fly ash addition) and fixation (addition of lime). The compressibility of stabilized sludge decreases as stabilization and fixation are increased.

TABLE III

LIME REGENERATED DUAL ALKALI:MOE LEACHATE EXTRACTION: ANALYTICAL RESULTSR.M. Schahfer Station 17 & 18, Northern Indiana Public Service Co. - Filter Cake

| Parameter                                                                  | Aerobic  |             | Backfill Use:<br>Max Acceptable<br>Extract Concentration (Mono-<br>fill Test)/32/ | Hazardous Waste<br>Categorization:<br>Max Extract Concentration for Exemption (Co-disposal Test) /33/ |
|----------------------------------------------------------------------------|----------|-------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
|                                                                            | Monofill | Co-Disposal |                                                                                   |                                                                                                       |
| pH                                                                         | 11.58    | 4.88        | -                                                                                 | -                                                                                                     |
| Specific Conductivity (mS/m)                                               | -        | NA          | -                                                                                 | -                                                                                                     |
| As                                                                         | <0.001   | <0.001      | 0.05                                                                              | 5                                                                                                     |
| Ba                                                                         | *        | *           | 1.0                                                                               | 100                                                                                                   |
| B                                                                          | 2.29     | 4.83        | 5.0                                                                               | 500                                                                                                   |
| Cd                                                                         | <0.0002  | 0.0006      | 0.005                                                                             | 0.5                                                                                                   |
| Cr (total) †                                                               | <0.2     | <0.2        | 0.05                                                                              | 5                                                                                                     |
| 'WAD' (CN)                                                                 | <0.04    | <0.04       | 0.2                                                                               | 20                                                                                                    |
| F <sup>-</sup>                                                             | 4.8      | 4.0         | 2.4                                                                               | 240                                                                                                   |
| Pb                                                                         | <0.002   | <0.005      | 0.05                                                                              | 5                                                                                                     |
| Hg                                                                         | <0.0002  | <0.0002     | 0.001                                                                             | 0.1                                                                                                   |
| NO <sub>3</sub> <sup>-</sup> (as N)                                        | 0.03     | 0.03        | 10.0                                                                              | 1000                                                                                                  |
| NO <sub>2</sub> <sup>-</sup> (as N)                                        | 0.015    | 0.006       | 1.0                                                                               | 100                                                                                                   |
| Total [NO <sub>3</sub> <sup>-</sup> +NO <sub>2</sub> <sup>-</sup> ] (as N) | 0.05     | 0.04        | 10.0                                                                              | 1000                                                                                                  |
| U †                                                                        | 0.03     | 0.03        | 0.02                                                                              | 2                                                                                                     |
| PCBs                                                                       | <0.001   | <0.001      | 0.003                                                                             | 0.3                                                                                                   |
| Se                                                                         | 0.002    | 0.002       | 0.01                                                                              | 1                                                                                                     |
| Ag                                                                         | <0.0005  | <0.0005     | 0.05                                                                              | 5                                                                                                     |
| Cl <sup>-</sup>                                                            | 33       | 35          | 1250                                                                              | -                                                                                                     |
| Cu                                                                         | <0.1     | <0.1        | 5.0                                                                               | -                                                                                                     |
| Fe                                                                         | <0.5     | <0.5        | 1.5                                                                               | -                                                                                                     |
| Mn                                                                         | <0.05    | 0.13        | 0.25                                                                              | -                                                                                                     |
| Organic N                                                                  | 0.42     | 1.73        | 0.75                                                                              | -                                                                                                     |
| Phenols                                                                    | <0.001   | *           | 0.01                                                                              | -                                                                                                     |
| SO <sub>4</sub> <sup>=</sup>                                               | 615      | 2300        | 2500                                                                              | -                                                                                                     |
| TDS                                                                        | -        | NA          | 2500                                                                              | -                                                                                                     |
| TOC                                                                        | -        | NA          | 25                                                                                | -                                                                                                     |
| Zn                                                                         | <0.02    | 0.2         | 25                                                                                | -                                                                                                     |
| NH <sub>3</sub>                                                            | <0.01    | 0.019       | -                                                                                 | -                                                                                                     |

All concentrations given in mg/L

† Analytical interference due to high background Ca concentrations

\* Result could not be obtained due to interferences

TABLE IV

LIME REGENERATED DUAL ALKALI:MOE LEACHATE EXTRACTION: ANALYTICAL RESULTS

R.M. Schahfer Station 17 & 18,  
Northern Indiana Public Service Co. - Stabilized Filter Cake

| Parameter                                                                  | Aerobic  |             | Backfill Use:<br>Max Acceptable<br>Extract Concentration (Mono-<br>fill Test)/32/ | Hazardous Waste<br>Categorization:<br>Max Extract Concentration for Exemption (Co-disposal Test)/33/ |
|----------------------------------------------------------------------------|----------|-------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
|                                                                            | Monofill | Co-Disposal |                                                                                   |                                                                                                      |
| pH                                                                         | 10.81    | 5.06        | -                                                                                 | -                                                                                                    |
| Specific Conductivity (mS/m)                                               | -        | NA          | -                                                                                 | -                                                                                                    |
| As                                                                         | 0.007    | 0.003       | 0.05                                                                              | 5                                                                                                    |
| Ba                                                                         | *        | *           | 1.0                                                                               | 100                                                                                                  |
| B                                                                          | 5.45     | 30.5        | 5.0                                                                               | 500                                                                                                  |
| Cd                                                                         | <0.0002  | 0.025       | 0.005                                                                             | 0.5                                                                                                  |
| Cr (total) †                                                               | 0.2      | 0.2         | 0.05                                                                              | 5                                                                                                    |
| 'WAD' (CN)                                                                 | 0.04     | 0.04        | 0.2                                                                               | 20                                                                                                   |
| F <sup>-</sup>                                                             | 0.62     | 2.8         | 2.4                                                                               | 240                                                                                                  |
| Pb                                                                         | <0.002   | <0.005      | 0.05                                                                              | 5                                                                                                    |
| Hg                                                                         | <0.0002  | 0.0009      | 0.001                                                                             | 0.1                                                                                                  |
| NO <sub>3</sub> <sup>-</sup> (as N)                                        | 0.03     | 0.03        | 10.0                                                                              | 1000                                                                                                 |
| NO <sub>2</sub> (as N)                                                     | 0.01     | 0.006       | 1.0                                                                               | 100                                                                                                  |
| Total [NO <sub>3</sub> <sup>-</sup> +NO <sub>2</sub> <sup>-</sup> ] (as N) | 0.04     | 0.04        | 10.0                                                                              | 1000                                                                                                 |
| U†                                                                         | 0.04     | 0.05        | 0.02                                                                              | 2                                                                                                    |
| PCBs                                                                       | <0.001   | <0.001      | 0.003                                                                             | 0.3                                                                                                  |
| Se                                                                         | 0.009    | 0.034       | 0.01                                                                              | 1                                                                                                    |
| Ag                                                                         | <0.0005  | <0.0005     | 0.05                                                                              | 5                                                                                                    |
| Cl <sup>-</sup>                                                            | 19       | 20          | 1250                                                                              | -                                                                                                    |
| Cu                                                                         | <0.1     | <0.1        | 5.0                                                                               | -                                                                                                    |
| Fe                                                                         | <0.5     | 2.5         | 1.5                                                                               | -                                                                                                    |
| Mn                                                                         | <0.05    | 1.59        | 0.25                                                                              | -                                                                                                    |
| Organic N                                                                  | 0.15     | 1.13        | 0.75                                                                              | -                                                                                                    |
| Phenols                                                                    | <0.001   | *           | 0.01                                                                              | -                                                                                                    |
| SO <sub>4</sub> <sup>=</sup>                                               | 763      | 2170        | 2500                                                                              | -                                                                                                    |
| TDS                                                                        | -        | NA          | 2500                                                                              | -                                                                                                    |
| TOC                                                                        | -        | NA          | 25                                                                                | -                                                                                                    |
| Zn                                                                         | <0.02    | 2.0         | 25                                                                                | -                                                                                                    |
| NH <sub>3</sub>                                                            | <0.01    | 0.019       | -                                                                                 | -                                                                                                    |

All concentrations given in mg/L

† Analytical interference due to high background Ca concentrations

\* Result could not be obtained due to interferences

TABLE V

LIME REGENERATED DUAL ALKALIMOE LEACHATE EXTRACTION: ANALYTICAL RESULTSNewton Station 1, Central Illinois Public Service Co. - Vacuum Drum Filter Cake

| Parameter                                                                  | Aerobic  |             | Backfill Use:<br>Max Acceptable<br>Extract Concentration (Monofill Test)/32/ | Hazardous Waste<br>Categorization:<br>Max Extract Concentration for Exemption (Co-disposal Test)/33/ |
|----------------------------------------------------------------------------|----------|-------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
|                                                                            | Monofill | Co-Disposal |                                                                              |                                                                                                      |
| pH                                                                         | 11.86    | 4.92        | -                                                                            | -                                                                                                    |
| Specific Conductivity (mS/m)                                               | -        | NA          | -                                                                            | -                                                                                                    |
| As                                                                         | <0.001   | <0.001      | 0.05                                                                         | 5                                                                                                    |
| Ba                                                                         | *        | *           | 1.0                                                                          | 100                                                                                                  |
| B                                                                          | 3.12     | 4.9         | 5.0                                                                          | 500                                                                                                  |
| Cd                                                                         | <0.0002  | 0.0006      | 0.005                                                                        | 0.5                                                                                                  |
| Cr (total) †                                                               | <0.2     | <0.2        | 0.05                                                                         | 5                                                                                                    |
| 'WAD' (CN)                                                                 | <0.04    | <0.04       | 0.2                                                                          | 20                                                                                                   |
| F <sup>-</sup>                                                             | -        | 9.8         | 2.4                                                                          | 240                                                                                                  |
| Pb                                                                         | <0.002   | <0.002      | 0.05                                                                         | 5                                                                                                    |
| Hg                                                                         | <0.0002  | <0.0002     | 0.001                                                                        | 0.1                                                                                                  |
| NO <sub>3</sub> <sup>-</sup> (as N)                                        | 0.08     | 0.14        | 10.0                                                                         | 1000                                                                                                 |
| NO <sub>2</sub> (as N)                                                     | 0.02     | 0.003       | 1.0                                                                          | 100                                                                                                  |
| Total [NO <sub>3</sub> <sup>-</sup> +NO <sub>2</sub> <sup>-</sup> ] (as N) | 0.10     | 0.14        | 10.0                                                                         | 1000                                                                                                 |
| U†                                                                         | 0.09     | 0.1         | 0.02                                                                         | 2                                                                                                    |
| PCBs                                                                       | <0.001   | <0.001      | 0.003                                                                        | 0.3                                                                                                  |
| Se                                                                         | 0.006    | 0.019       | 0.01                                                                         | 1                                                                                                    |
| Ag                                                                         | <0.0005  | <0.0005     | 0.05                                                                         | 5                                                                                                    |
| Cl <sup>-</sup>                                                            | 475      | 485         | 1250                                                                         | -                                                                                                    |
| Cu                                                                         | <0.1     | <0.1        | 5.0                                                                          | -                                                                                                    |
| Fe                                                                         | <0.5     | 1.6         | 1.5                                                                          | -                                                                                                    |
| Mn                                                                         | 0.05     | 0.05        | 0.25                                                                         | -                                                                                                    |
| Organic N                                                                  | 2.35     | 2.6         | 0.75                                                                         | -                                                                                                    |
| Phenols                                                                    | <0.01    | *           | 0.01                                                                         | -                                                                                                    |
| SO <sub>4</sub> <sup>=</sup>                                               | 1475     | 2815        | 2500                                                                         | -                                                                                                    |
| TDS                                                                        | -        | NA          | 2500                                                                         | -                                                                                                    |
| TOC                                                                        | -        | NA          | 25                                                                           | -                                                                                                    |
| Zn                                                                         | <0.02    | 0.55        | 25                                                                           | -                                                                                                    |
| NH <sub>3</sub>                                                            | <0.01    | 0.009       | -                                                                            | -                                                                                                    |

All concentrations given in mg/L

† Analytical interference due to high background Ca concentrations

\* Result could not be obtained due to interferences

TABLE VI

LIME REGENERATED DUAL ALKALI:MOE LEACHATE EXTRACTION: ANALYTICAL RESULTS

Newton Station 1, Central Illinois Public Service Co.  
- (POZ-O-TEC Material)

| Parameter                                                                  | Aerobic  |             | Backfill Use:<br>Max Acceptable<br>Extract Concentration (Mono-<br>fill Test)/32/ | Hazardous Waste<br>Categorization:<br>Max Extract Concentration for Exemption (Co-disposal Test)/33/ |
|----------------------------------------------------------------------------|----------|-------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
|                                                                            | Monofill | Co-Disposal |                                                                                   |                                                                                                      |
| pH                                                                         | 12.17    | 6.3         | -                                                                                 | -                                                                                                    |
| Specific Conductivity (mS/m)                                               | -        | NA          | -                                                                                 | -                                                                                                    |
| As                                                                         | 0.003    | <0.001      | 0.05                                                                              | 5                                                                                                    |
| Ba                                                                         | *        | *           | 1.0                                                                               | 100                                                                                                  |
| B                                                                          | 0.17     | 16.6        | 5.0                                                                               | 500                                                                                                  |
| Cd                                                                         | <0.0002  | 0.040       | 0.005                                                                             | 0.5                                                                                                  |
| Cr (total) †                                                               | <0.2     | <0.2        | 0.05                                                                              | 5                                                                                                    |
| 'WAD' (CN)                                                                 | <0.04    | <0.04       | 0.2                                                                               | 20                                                                                                   |
| F <sup>-</sup>                                                             | 0.5      | 2.1         | 2.4                                                                               | 240                                                                                                  |
| Pb                                                                         | <0.002   | <0.002      | 0.05                                                                              | 5                                                                                                    |
| Hg                                                                         | <0.0002  | <0.0002     | 0.001                                                                             | 0.1                                                                                                  |
| NO <sub>3</sub> <sup>-</sup> (as N)                                        | 0.07     | 0.11        | 10.0                                                                              | 1000                                                                                                 |
| NO <sub>2</sub> <sup>-</sup> (as N)                                        | 0.04     | 0.03        | 1.0                                                                               | 100                                                                                                  |
| Total [NO <sub>3</sub> <sup>-</sup> +NO <sub>2</sub> <sup>-</sup> ] (as N) | 0.11     | 0.14        | 10.0                                                                              | 1000                                                                                                 |
| U†                                                                         | 0.03     | 0.08        | 0.02                                                                              | 2                                                                                                    |
| PCBs                                                                       | <0.001   | <0.001      | 0.003                                                                             | 0.3                                                                                                  |
| Se                                                                         | 0.003    | 0.003       | 0.01                                                                              | 1                                                                                                    |
| Ag                                                                         | <0.0005  | <0.0005     | 0.05                                                                              | 5                                                                                                    |
| Cl <sup>-</sup>                                                            | 170      | 160         | 1250                                                                              | -                                                                                                    |
| Cu                                                                         | <0.1     | <0.1        | 5.0                                                                               | -                                                                                                    |
| Fe                                                                         | <0.5     | 1.3         | 1.5                                                                               | -                                                                                                    |
| Mn                                                                         | <0.05    | 1.5         | 0.25                                                                              | -                                                                                                    |
| Organic N                                                                  | 0.9      | 2.78        | 0.75                                                                              | -                                                                                                    |
| Phenols                                                                    | <0.001   | 0.002       | 0.01                                                                              | -                                                                                                    |
| SO <sub>4</sub> <sup>=</sup>                                               | 1045     | 1340        | 2500                                                                              | -                                                                                                    |
| TDS                                                                        | -        | NA          | 2500                                                                              | -                                                                                                    |
| TOC                                                                        | -        | NA          | 25                                                                                | -                                                                                                    |
| Zn                                                                         | <0.02    | 1.27        | 25                                                                                | -                                                                                                    |
| NH <sub>3</sub>                                                            | 0.011    | 0.015       | -                                                                                 | -                                                                                                    |

All concentrations given in mg/L

† Analytical interference due to high background Ca concentrations

\* Result could not be obtained due to interferences

- iii) Stabilization with fly ash (no lime fixation) has little effect on either peak or steady-state concentrations of leachate constituents.
- iv) Generally, the higher the lime content, the longer the time to develop the maximum cured unconfined compressive strength. Thus, for 1-3% lime, a 28-day curing period was sufficient. Mixes with 5% lime required 56 days or longer before developing maximum strength. Moreover, a landfill with thin lifts during placement, allowing time for air-drying before deposition of the next layer, was predicted to have the highest strength during reclamation.
- v) The effect of lime fixation is greatest on steady-state leachate concentrations of TDS,  $\text{SO}_4$  and Ca. Fixation with 1% lime reduces concentrations of major constituents as effectively as fixation with 5% lime. However, additional amounts of lime may reduce concentrations of minor and trace metals in the leachate. (While no explanation was given, it may be that concentrations of Ca and sulphate, major contributors to TDS, are limited by the solubility of  $\text{CaSO}_4$ . Additional lime may suppress the solubility of most trace metals, which tend to precipitate as hydroxides at elevated pH.)
- vi) Unstabilized filter cake coefficients of permeability ranged from  $3.8 \times 10^{-5}$  to  $4.0 \times 10^{-6}$  cm/s for solid contents of 47 to 67% respectively. For stabilized sludge, permeability decreased with time, eg, with lime contents of 3-5%, permeability decreased 100-fold after curing/fixation was completed.

Based on laboratory measurements, predicted engineering properties of a field-worthy sample (described above) are given in Table VII.

Analyses of leachates from the Scholtz disposal site and of the field-worthy sample are given in Table VIII.

### 3.3. Summary and Conclusions

A key feature of the Dual Alkali FGD Process is economic, efficient recovery of reagent sodium values in the regenerant sludge dewatering filtration step. While this has been effectively attained using lime as regenerant, there is (at least) one claim that use of limestone as regenerant can lead to relatively poor dewatering characteristics. Presence of magnesium in the lime/limestone regenerant can, moreover, lead to precipitation of magnesium hydroxide, which blinds the vacuum filter cloth. On the whole, the question of whether the cost advantage inherent in limestone regeneration is offset by dewatering problems during sludge handling can only be answered on a case-by-case basis. Landfill of the solid waste, typically containing a calcium sulphite to calcium sulphate molar ratio of at least 4 to 1, should be accompanied by monitoring, and where necessary, treatment of leachate to meet applicable ground and surface water environmental standards.

Table VII  
ENGINEERING PROPERTIES OF SCHOLTZ DUAL ALKALI WASTE SELECTED SAMPLES/18/

| Parameter                              | Units              | Initial Disposal Waste | Final Disposal Waste | Predicted Field Values of Field-Worthy Sample       |
|----------------------------------------|--------------------|------------------------|----------------------|-----------------------------------------------------|
| Solids Content                         | %                  | 40-45                  | same                 | 56                                                  |
| Fly Ash to Filter Cake Ratio           | -                  | 0.8                    | same                 | 1.0 or greater                                      |
| Lime Content                           | %                  | 3-4                    | same                 | 3                                                   |
| Liquid Limit                           | %                  | 50                     | 50                   | 50                                                  |
| Natural Water Content                  | %                  | 69                     | 45.3                 | 38.1                                                |
| Optimum Water Content                  | %                  | 35-25                  | 35-25                | 36.5                                                |
| Maximum Actual Dry Density             | kg/m <sup>3</sup>  | 1,250-1,400            | 1,250-1,400          | 1,230                                               |
| Friction Angle                         | degrees            | -                      | 42.8                 | 40-42                                               |
| Cohesion Intercept                     | kg/cm <sup>2</sup> | -                      | 0.07                 | 0                                                   |
| Unconfined Compressive Strength        | kg/cm <sup>2</sup> | .001                   | 1.0-3.0              | 0.2-4.0<br>(0-28 days)                              |
| Permeability                           | cm/s               | -                      | $3 \times 10^{-6}$   | $10^{-5} - 10^{-6}$                                 |
| Compressibility Ratio                  | -                  |                        |                      | 0.005-0.1<br>(for 0.2-10 kg/cm <sup>2</sup> stress) |
| Coefficient of Primary Consolidation   | cm <sup>2</sup> /s | -                      | -                    | 0.1                                                 |
| Coefficient of Secondary Consolidation | %                  | -                      | -                    | 0.2-0.3                                             |

Table VIII

TRACE ELEMENT ANALYSIS OF LEACHATES FROM SCHOLZ  
DUAL ALKALI WASTE DISPOSAL SITE AND FIELD-WORTHY SAMPLE/18/

| Parameter | Leachate*<br>From<br>Site | Field-Worthy<br>Sample **<br>(EPA/EP Test) | EPA Interim<br>Primary Drinking<br>Water Standard | EPA Secondary Drinking<br>Water Standard |
|-----------|---------------------------|--------------------------------------------|---------------------------------------------------|------------------------------------------|
| Aluminum  | 1.5                       | 6.8                                        | -                                                 | -                                        |
| Calcium   | 130                       | 1155                                       | -                                                 | -                                        |
| Iron      | 0.13                      | 12.7                                       | -                                                 | 0.3                                      |
| Magnesium | 5.6                       | 30.0                                       | -                                                 | -                                        |
| Potassium | 480                       | 33.3                                       | -                                                 | -                                        |
| Sodium    | 15,000                    | 735                                        | -                                                 | -                                        |
| Beryllium | <0.01                     | .010                                       | -                                                 | -                                        |
| Boron     | -                         | 2.57                                       | -                                                 | -                                        |
| Silicon   | 4.6                       | 515                                        | -                                                 | -                                        |
| Cadmium   | <.01                      | 0.02                                       | 0.01                                              | -                                        |
| Chromium  | <.05                      | 0.10                                       | 0.05                                              | -                                        |
| Copper    | <.01                      | 0.08                                       | -                                                 | 1                                        |
| Lead      | <.05                      | 0.14                                       | 0.05                                              | -                                        |
| Manganese | 0.65                      | 0.47                                       | -                                                 | 0.05                                     |
| Nickel    | <.05                      | 0.22                                       | -                                                 | -                                        |
| Zinc      | 0.11                      | 0.27                                       | -                                                 | 5                                        |
| Arsenic   | 22†                       | 0.04                                       | 0.05                                              | -                                        |
| Selenium  | 0.63                      | 0.004                                      | 0.01                                              | -                                        |
| Mercury   | 0.001                     | 0.014                                      | 0.002                                             | -                                        |

Notes:

\* Leachate collected from Scholz disposal site on May 29, 1981.

\*\* Scholz laboratory mixture with fly ash-to-filter cake ratio of 1:1, 3% lime addition, and 56% solids content.

† The high arsenic value measured in the field leachate was not found in any of the stabilized sludge leachate samples from the laboratory testing program.

#### 4.0 LIME SPRAY DRYING FGD WASTES

##### 4.1 Typical Process Description

When a lime slurry is atomized into a spray dryer, where it contacts a utility flue gas stream, the mist is rapidly dried by the heat of the flue gas. During this drying process, the alkaline material in the mist reacts with sulphur oxides in the flue gas to form an intimate mixture of fine calcium sulphite (major product) and calcium sulphate (minor product) particles. The solid product collects in hoppers at the base of the spray dryer and/or downstream in an electrostatic precipitator or filter fabric baghouse together with the regular (unremoved) fly ash. Here further  $SO_2$  removal takes place as unreacted sorbent in the waste combines with remaining  $SO_2$  in the flue gas. The dry waste collected can be disposed of, utilized, or mixed into a slurry for recycle back to the spray dryer. Advantages of lime spray drying wastes over wet scrubbing FGD wastes are:

- i) The dry waste obviates the complexity and operating problems associated with large volumes of liquid waste typically produced in wet scrubbing FGD systems, and
- ii) The dry waste can be landfilled directly. (Depending on a combination of original coal quality, system design and operating conditions, it will contain various proportions of  $CaSO_3$ ,  $CaSO_4$ , unreacted  $Ca(OH)_2$ ,  $CaCO_3$  and fly ash).

Whereas many wet scrubber FGD systems use relatively inexpensive limestone, a disadvantage of lime spray drying in relation to wet scrubbing FGD is that spray drying requires the usually more expensive sorbent slaked lime to attain high  $SO_2$  removal efficiencies.

##### 4.2 Waste Properties

The properties of a given lime spray dryer waste depend on the particular waste management system used. This includes the equipment and operating procedure needed to:

- i) remove the waste from the spray dryer hopper or particulate collector,
- ii) transfer, store and condition the waste,
- iii) transport the waste to the final disposal area,
- iv) place and contain the waste at the disposal site.

These subsystems are interdependent: selection of the "right" combination for a particular management system affects and is affected by the waste properties at each stage of handling and disposal.

In a recent study/19/ both physical and chemical tests were performed on eight lime spray dryer wastes from seven facilities in the USA to try and define representative characteristics. All of the fuels were either lignite or sub-bituminous coal, with average sulphur contents generally <1% w/w.

#### 4.2.1 Physical Properties

These can be divided into those that affect (i) storage, (ii) transfer and transport and/or (iii) disposal.

##### 4.2.1.1 Storage

Lime spray dryer wastes flow readily, largely due to their low (1-2% w/w) moisture content. They also aerate easily, useful if controlled fluidized handling is to be used.

##### 4.2.1.2 Transfer and Transport

Lime spray dryer wastes are abrasive, and have worn equipment at some facilities. They are also hygroscopic, and may become tacky, with solids build-up at elbows of pneumatic equipment and on mechanical conveyors unless precautions are taken to avoid wetting.

Other properties that affect transfer and transport include:

###### (a) Particle Size

Lime spray dryer wastes tend to have smaller mean particle size than regular fly ash. For example, in one study/19/ mean particle size of spray dryer wastes varied from 20-28  $\mu\text{m}$  (averaging 23.3  $\mu\text{m}$ ). Conventional ash from the same study without the spray dryer operating had a mean particle size of 45  $\mu\text{m}$ .

###### (b) Bulk Density

The poured bulk density of the same waste/19/ ranged from 580-790  $\text{kg/m}^3$ . Its packed (tapped) bulk density ranged from 780-1,020  $\text{kg/m}^3$ . The dry density of lime spray drier waste derived from a high sulphur coal has been reported/20/ to be 1,230  $\text{kg/m}^3$ .

##### 4.2.1.3 Disposal

Properties that affect disposal include:

###### (a) Optimum Moisture/Maximum Densities (Proctor Test)

Typical optimum moisture values/19/ ranged from 16-38%, averaging 28.5%. These are high compared with regular fly ash, and are thought to result from differences in chemical character, with different water uptake requirements

for hydration and fixation reactions. The corresponding maximum dry densities ranged from 1142-1666 kg/m<sup>3</sup>, averaging 1373 kg/m<sup>3</sup>. A typical dry density for the waste derived from a high sulphur coal was reported/20/ to be 1230 kg/m<sup>3</sup>. These values are of use in sizing and designing the waste disposal area.

#### (b) Unconfined Compressive Strength

For low sulphur coal-derived spray dryer waste, moistened and cured (28-day) compressive strengths of 2-9 MPa were reported/19/, ie, suitable for landfill construction purposes. The unconfined compressive strength for the waste derived from a high sulphur coal was reported to be 1.4 to 6.9 MPa for 28-56 days curing following moist compaction/20/.

#### (c) Permeability

Studies/21,22/ have shown permeability as low as  $2.7 \times 10^{-7}$  cm/s for low sulphur coal-derived lime spray dryer wastes. Since a maximum permeability of  $1 \times 10^{-7}$  cm/s is required by the EPA for landfill liners for hazardous wastes, these wastes may not require a separate liner. For lime spray dryer waste derived from a high sulphur coal, 7-day cure permeabilities of  $5 \times 10^{-5}$  to  $1 \times 10^{-6}$  cm/s have been reported/20/. These values would be expected to drop considerably on longer curing.

#### 4.2.2 Chemical Properties

These can be subdivided into (i) composition of the lime spray dryer solids and (ii) leachate characteristics.

##### 4.2.2.1 Composition of Lime Spray Dryer Solid Wastes

Lime spray dryer wastes consist of spherical glassy fly ash particles (cenospheres) coated by and intermixed with fine crystals of calcium/sulphur reaction by-products, eg calcium sulphite and calcium sulphate. Since conventional fly ash is a major component of these wastes, the latter somewhat resemble regular fly ash. However, spray dryer wastes are finer and more alkaline, have a significant heat of hydration, and give a more alkaline leachate compared to regular fly ash.

A typical lime spray dryer waste composition of 75% w/w fly ash; 16% w/w  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ; 6% w/w  $\text{CaSO}_3 \cdot 1/2 \text{H}_2\text{O}$ ; 2% w/w  $\text{Ca}(\text{OH})_2$ ; and 1% w/w moisture has been reported/23/. This waste was derived from combustion of coal containing 8% w/w ash and 0.7% w/w sulphur, in a unit achieving 70%  $\text{SO}_2$  removal.

A typical chemical analysis of lime spray dryer solids, based on the eight waste samples indicated above/19/ is given in Table IX. Elements found in the highest concentrations were Al, Ca, Fe, Mg, Si and Na. Of these, the Al, Fe and Si are attributable to the wastes' high fly ash content. The higher Ca content reflects the lime added in the spray drier for  $\text{SO}_2$  removal. The high alkalinity of the waste (shown by the high Ca, Mg and Na contents) indicates potential additional  $\text{SO}_2$  removal capability.

Table IX  
CALCIUM SPRAY DRYER WASTES  
CHEMICAL CHARACTERIZATION OF SOLIDS/19/  
(mg/kg except where noted)

| <u>Inorganic Elements (ICPES)</u> | <u>Range</u>     |
|-----------------------------------|------------------|
| Aluminum                          | 33,300 - 66,700  |
| Antimony                          | 5.6* - 29        |
| Arsenic                           | <12 - 22*        |
| Barium                            | 190 - 3390       |
| Beryllium                         | 1.4 - 3.1        |
| Boron                             | <10 - 230        |
| Cadmium                           | <0.4 - 5.8       |
| Calcium                           | 14,300 - 223,000 |
| Chromium                          | 36 - 210         |
| Cobalt                            | 9.9 - 26         |
| Copper                            | 20 - 160         |
| Iron                              | 10,900 - 53,700  |
| Lead                              | <16 - 46*        |
| Lithium                           | 18 - 42          |
| Magnesium                         | 3880 - 27,700    |
| Manganese                         | 55 - 680         |
| Molybdenum                        | 2.7 - 514        |
| Nickel                            | 17 - 110         |
| Potassium                         | 1760 - 7020      |
| Selenium                          | 71* - 280        |
| Silicon                           | 72,800 - 120,000 |
| Silver                            | 1.6* - 5.8       |
| Sodium                            | 6540 - 34,000    |
| Strontium                         | 184 - 3040       |
| Thallium                          | <18              |
| Tin                               | <19 - 349        |
| Titanium                          | 1610 - 5360      |
| Uranium                           | <5 - 140         |
| Vanadium                          | 72 - 180         |
| Zinc                              | 22 - 110         |
| <u>Volatile Metals (AA)</u>       |                  |
| Arsenic                           | 3.6 - 48         |
| Cadmium                           | 0.2* - 0.63      |
| Lead                              | <0.3 - 19        |
| Mercury                           | <0.05 - 0.39     |
| Selenium                          | <0.4 - 7.3*      |
| <u>Soluble Anions</u>             |                  |
| Carbonate (Titration)             | 5* - 8.5*        |
| Chloride (Ion Chromatography)     | 0.4 - 4.4        |
| Fluoride (Ion Specific Electrode) | 0.5 - 1.1        |
| Hydroxide (Titration) (mg/g)      | 5.1 - 83         |
| Sulfite (Titration)               | 47 - 173         |
| Total Sulfur (Ion Chromatography) | 51 - 134         |

\*Value is less than 5 times the detection limit.

#### 4.2.2.2 Leachate Analysis

Both the EPA/EP toxicity leach tests and ASTM leachate extraction tests were carried out on the eight lime spray dryer waste samples/19/, and the results are given in Table X. The first eight species listed are used by the EPA to classify materials as hazardous (ie, leachate toxic). It is apparent that the wastes examined would not be considered leachate toxic under US federal regulations. Other contaminants, of possible environmental significance with respect to US Federal drinking water standards, are also given in Table X. Some of the lime spray dryer waste extracts were found to exceed US Federal drinking water standards for TDS,  $\text{Cl}^-$ , Mn, pH,  $\text{SO}_4$ ,  $\text{NO}_3^-$  and  $\text{NO}_2^-$ . However, if 100 times the U.S. drinking water standards are used as a regulatory limit, then only the  $\text{NO}_2^-$  concentrations would be exceeded/19/.

A sample of lime spray dryer baghouse ash was obtained from the Holcomb Station, Kansas, USA. The waste was subjected at Ontario Hydro Research Division to the Ontario MOE Leachate Extraction Procedure. It was found that the material was non-"leachate toxic", and would be acceptable for backfill use in the Province of Ontario (Table XI).

#### 4.3 Lime Spray Dryer Installations

A summary of planned and existing utility lime spray dryer systems reported in detail to date/19/ is given in Table XII. Details of existing utility lime spray dryer waste management systems are summarized in Table XIII.

##### 4.3.1 Riverside Station Spray Dryer Tests

In a programme co-funded by the US EPA and EPRI, a short-duration, full scale utility lime spray dryer/baghouse system was tested/24/ in 1983 at the Northern States Power Company's Riverside Station. Two different coals were used as boiler fuels. One was a sub-bituminous coal/coke mixture with a nominal 1.2% sulphur content. The other was a 3.4% sulphur Illinois bituminous coal. For the low sulphur coal, 75%  $\text{SO}_2$  removal was obtained at Ca/S ratios of 0.6-0.7, and 90%  $\text{SO}_2$  removal achieved at a Ca/S ratio of 0.8.  $\text{SO}_2$  removals of ~ 90% were achieved with high sulphur coal at Ca/S ratios of 1.3-1.4. Calcium chloride addition to the atomizer feed slurry reduced the lime requirements by ~ 25% in high sulphur tests. Chemical analyses are given in Table XIV for each solid waste sample. Percent moisture and unconfined compressive strength data are given in Table XV. Permeability data are given in Table XVI. US EPA/EP toxicity tests of the "as received" wastes yielded extracts with analytical results as summarized in Table XVII for eight species of concern to the EPA. All waste samples met the requirements for classification as 'non-hazardous' wastes in terms of the EP leachate toxicity test.

The effects of curing on the EP extracts of the waste solids is indicated in Table XVIII. It is noteworthy that, in the EP extract of high sulphur coal (without  $\text{Cl}^-$  addition), Al, Mg, Mn, Ni, K, Si, Na, Sr and Zn were

TABLE X

LEACHATE ANALYSIS OF CALCIUM SPRAY DRYER WASTES/19/  
(Concentrations in mg/L Except for pH)

| Reference<br>Concentration<br>Level | Argonite |                     | Stenton             |                    | Laramie |                     | Holtcomb            |         | Argonite II         |                    | Valley             |                    | Rushville         |                    | Antelope           |                   |
|-------------------------------------|----------|---------------------|---------------------|--------------------|---------|---------------------|---------------------|---------|---------------------|--------------------|--------------------|--------------------|-------------------|--------------------|--------------------|-------------------|
|                                     | EP       | ASTM                | EP                  | ASTM               | EP      | ASTM                | EP                  | ASTM    | EP                  | ASTM               | EP                 | ASTM               | EP                | ASTM               | EP                 | ASTM              |
| EP Toxicity<br>Direct Ingestion     |          |                     |                     |                    |         |                     |                     |         |                     |                    |                    |                    |                   |                    |                    |                   |
| Arsenic                             | 5.0      | <0.002              | <0.002              | <0.003             | <0.003  | <0.003              | 0.004 <sup>a</sup>  | 0.005   | <0.005              | <0.003             | <0.003             | <0.002             | <0.005            | <0.002             | 0.016              | <0.002            |
| Barium                              | 100      | 1.5                 | 2.7                 | 0.80               | 0.61    | 0.67                | 0.73                | 0.92    | 0.38                | 0.40               | 0.42               | 0.42               | 0.1               | 0.19               | 0.29               | 0.27              |
| Cadmium                             | 1.0      | 0.0004 <sup>a</sup> | 0.0001 <sup>a</sup> | <0.0005            | <0.0005 | <0.0005             | <0.0005             | <0.0005 | 0.0006 <sup>a</sup> | <0.0005            | <0.004             | <0.0005            | <0.004            | <0.004             | <0.004             | <0.004            |
| Chromium                            | 5.0      | 0.13                | 0.34                | 0.069              | 0.28    | 0.28                | 0.016               | 0.51    | 0.019               | 0.12               | 0.21               | 0.32               | 0.11              | 0.29               | 0.028              | 0.31              |
| Lead                                | 5.0      | <0.002              | <0.002              | <0.002             | <0.002  | <0.002              | <0.002              | <0.002  | <0.002              | <0.002             | <0.002             | 0.008 <sup>a</sup> | <0.002            | <0.002             | <0.002             | <0.002            |
| Mercury                             | 0.2      | <0.0002             | <0.0002             | <0.0002            | <0.0002 | <0.0002             | 0.0005 <sup>a</sup> | <0.0002 | <0.0002             | <0.0002            | <0.0002            | <0.0002            | <0.0002           | <0.0002            | <0.0002            | <0.0002           |
| Selenium                            | 1.0      | <0.002              | 0.012 <sup>a</sup>  | 0.003 <sup>a</sup> | 0.011   | 0.011               | 0.034               | 0.055   | 0.009 <sup>a</sup>  | <0.003             | 0.047              | 0.1                | 0.025             | 0.021              | 0.045 <sup>a</sup> | 0.14              |
| Silver                              | 5.0      | <0.003              | 0.009 <sup>a</sup>  | 0.027              | 0.022   | 0.022               | 0.037               | 0.12    | 0.016               | 0.048              | 0.066              | 0.37               | 0.028             | 0.18               | 0.053              | 0.29              |
| Leaching Water<br>Scrubbers         |          |                     |                     |                    |         |                     |                     |         |                     |                    |                    |                    |                   |                    |                    |                   |
| Chloride                            | 250      | 10                  | 27                  | 15                 | 32      | 46                  | 25                  | 33      | 19                  | 18                 | 110                | 330                | 19                | 36                 | 20                 | 49                |
| Copper                              | 1        | 0.003 <sup>a</sup>  | 0.007 <sup>a</sup>  | 0.15               | 0.16    | 0.012               | 0.026               | 0.083   | 0.007               | 0.032              | 0.042              | 0.25               | 0.02              | 0.12               | 0.035              | 0.18              |
| Iron                                | 0.3      | 0.055               | 0.14                | 0.043              | 0.070   | 0.024 <sup>a</sup>  | 0.054               | 0.037   | 0.13                | 0.016              | 0.036 <sup>a</sup> | 0.2 <sup>a</sup>   | 0.01 <sup>a</sup> | 0.084              | 0.049              | <0.25             |
| Manganese                           | 0.05     | <0.001              | 0.002 <sup>a</sup>  | 0.006              | 0.22    | <0.005 <sup>a</sup> | 0.15                | 0.012   | 0.19                | 0.006              | 0.009              | 0.04 <sup>a</sup>  | 0.034             | 0.016              | 0.38               | 0.03 <sup>a</sup> |
| pH                                  | 6.5-8.5  | 11.0                | 11.9                | 11.45              | 11.4    | 11.0                | 8.45                | 9.8     | 7.65                | 11.35              | 12.0               | 12.1               | 8.7               | 11.7               | 8.4                | 11.6              |
| Sulfate                             | 250      | 231                 | 400                 | 380                | 1,000   | 220                 | 1,800               | 2,400   | 1,000               | 320                | 650                | 1,300              | 2,000             | 1,000              | 2,100              | 3,300             |
| TDS                                 | 500      | 9,100               | 2,800               | 9,990              | 3,790   | 9,040               | 105,000             | 4,550   | 9,380               | 2,180              | 9,800              | 5,200              | 12,000            | 2,800              | 10,000             | 6,000             |
| Zinc                                | 5        | <0.003              | 0.010               | 0.008 <sup>a</sup> | 0.045   | 0.009 <sup>a</sup>  | 0.015               | 0.22    | 0.064               | 0.011 <sup>a</sup> | 0.012 <sup>a</sup> | 0.09 <sup>a</sup>  | 0.01 <sup>a</sup> | 0.035 <sup>a</sup> | <0.003             | 0.08 <sup>a</sup> |
| Micrograms                          | 10       | 12                  | 67                  | 43                 | 110     | 10                  | 21                  | 200     | 3.5                 | 10                 | 6.8                | 33                 | 78                | 200                | 12                 | 31                |
| Micrograms                          | 1.0      | 29                  | 160                 | 20                 | 52      | 18                  | 32                  | 8       | 15.2                | 36                 | 1.9                | <2                 | 19                | 41                 | <1                 | <2                |

<sup>a</sup> Value is less than SE of the detection limit  
see Appendix

TABLE XI

LIME SPRAY DRYER, HOLCOMB STATION:MOE LEACHATE EXTRACTION: ANALYTICAL RESULTSSunflower Electric Cooperative, Inc., Kansas - Baghouse Ash

| Parameter                                                                  | Aerobic  |             | Backfill Use:<br>Max Acceptable<br>Extract Concentration (Mono-<br>fill Test)/32/ | Hazardous Waste<br>Categorization:<br>Max Extract Concentration for Exemption (Co-disposal Test)/33/ |
|----------------------------------------------------------------------------|----------|-------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
|                                                                            | Monofill | Co-Disposal |                                                                                   |                                                                                                      |
| pH                                                                         | 10.69    | 8.56        | -                                                                                 | -                                                                                                    |
| Specific Conductivity (mS/m)                                               |          | NA          | -                                                                                 | -                                                                                                    |
| As                                                                         | <0.001   | <0.002      | 0.05                                                                              | 5                                                                                                    |
| Ba                                                                         | *        | *           | 1.0                                                                               | 100                                                                                                  |
| B                                                                          | 0.75     | 8.4         | 5.0                                                                               | 500                                                                                                  |
| Cd                                                                         | <0.0002  | <0.0002     | 0.005                                                                             | 0.5                                                                                                  |
| Cr (total) †                                                               | <0.2     | <0.2        | 0.05                                                                              | 5                                                                                                    |
| 'WAD' (CN)                                                                 | <0.04    | <0.04       | 0.2                                                                               | 20                                                                                                   |
| F <sup>-</sup>                                                             | <0.5     | 3.0         | 2.4                                                                               | 240                                                                                                  |
| Pb                                                                         | <0.002   | <0.005      | 0.05                                                                              | 5                                                                                                    |
| Hg                                                                         | <0.0002  | 0.0015      | 0.001                                                                             | 0.1                                                                                                  |
| NO <sub>3</sub> <sup>-</sup> (as N)                                        | 4.77     | 8.88        | 10.0                                                                              | 1000                                                                                                 |
| NO <sub>2</sub> <sup>-</sup> (as N)                                        | 0.31     | 0.72        | 1.0                                                                               | 100                                                                                                  |
| Total [NO <sub>3</sub> <sup>-</sup> +NO <sub>2</sub> <sup>-</sup> ] (as N) | 5.07     | 9.60        | 10.0                                                                              | 1000                                                                                                 |
| U†                                                                         | 0.05     | 0.04        | 0.02                                                                              | 2                                                                                                    |
| PCBs                                                                       | <0.001   | <0.001      | 0.003                                                                             | 0.3                                                                                                  |
| Se                                                                         | 0.051    | 0.052       | 0.01                                                                              | 1                                                                                                    |
| Ag                                                                         | <0.0005  | <0.0005     | 0.05                                                                              | 5                                                                                                    |
| Cl <sup>-</sup>                                                            | 30       | 40          | 1250                                                                              | -                                                                                                    |
| Cu                                                                         | 0.1      | <0.1        | 5.0                                                                               | -                                                                                                    |
| Fe                                                                         | <0.5     | <0.5        | 1.5                                                                               | -                                                                                                    |
| Mn                                                                         | 0.05     | 0.05        | 0.25                                                                              | -                                                                                                    |
| Organic N                                                                  | 0.11     | 3.31        | 0.75                                                                              | -                                                                                                    |
| Phenols                                                                    | <0.001   | <0.001      | 0.01                                                                              | -                                                                                                    |
| SO <sub>4</sub> <sup>-</sup>                                               | 815      | 1630        | 2500                                                                              | -                                                                                                    |
| TDS                                                                        |          | NA          | 2500                                                                              | -                                                                                                    |
| TOC                                                                        |          | NA          | 25                                                                                | -                                                                                                    |
| Zn                                                                         | <0.02    | <0.02       | 25                                                                                | -                                                                                                    |
| NH <sub>3</sub>                                                            | 0.90     | 0.58        | -                                                                                 | -                                                                                                    |

All concentrations given in mg/L

† Analytical interference due to high background Ca concentrations

\* Result could not be obtained due to interferences

TABLE XII

## SUMMARY OF UTILITY CALCIUM SPRAY DRYER SYSTEMS /19/

| Utility                          | Station and Unit      | Location           | Capacity (MW) | New or Dryer Retrofit Start-Up Date | Fuel Type         | Avg. Sulfur Ash (%)      | Design SO <sub>2</sub> Removal (%) | Stochastic-Removal Rate | Baghouse/ESP | Dusts Film               |                                    |                                            |
|----------------------------------|-----------------------|--------------------|---------------|-------------------------------------|-------------------|--------------------------|------------------------------------|-------------------------|--------------|--------------------------|------------------------------------|--------------------------------------------|
|                                  |                       |                    |               |                                     |                   |                          |                                    |                         |              | Collected in Spray Dryer | Collected in Particulate Collector | Part. Dryer Collect. Spray Solids Recycled |
| Existing Systems                 |                       |                    |               |                                     |                   |                          |                                    |                         |              |                          |                                    |                                            |
| Basin Electric Power             | Antelope Valley 1     | Buolah, ND         | 440           | M                                   | 5-83              | MD Lignite               | 0.68                               | 7.8                     | 81 Avg.      | 0.9                      | 0                                  | 0                                          |
| Basin Electric Power             | Antelope Valley 2     | Buolah, ND         | 440           | M                                   | 11-85             | MD Lignite               | 0.68                               | 7.8                     | 89 Max.      | M.R.                     | 0                                  | Var.                                       |
| Basin Electric Power             | Laramie River 3       | Mustang, WY        | 575           | M                                   | 4-82              | WY Subbit. Coal          | 0.54                               | 7.9                     | 82 Avg.      | M.R.                     | 0                                  | 0.7                                        |
| Colorado-Like Electric Assoc.    | Craig 3               | Craig, CO          | 600           | M                                   | 10-84             | W. Subbit. Coal          | 0.4                                | 5                       | 87           | 2.0                      | 0                                  | 30-50                                      |
| Grand R. Dam Auth. - State of OK | Pryor 3               | Pryor, OK          | 520           | M                                   | 3-85              | W. Subbit. Coal          | 0.9                                | 7                       | 85           | M.R.                     | M.R.                               | M.R.                                       |
| Nazquette Board of Light & Power | Shiras 3              | Nazquette, HI      | 44            | M                                   | 4-83              | W. Subbit. Coal          | 0.5                                | 10.2                    | 80           | 1.4                      | 0                                  | 0                                          |
| Northern States Power Co.        | Riverside 6 & 7       | Minneapolis, MN    | 100           | R                                   | 10-80             | W. Subbit. Coal and Coko | 1.2                                | 8.9                     | 90 Max.      | 0.7                      | 0 <sup>b</sup>                     | Var.                                       |
| Platte River Power Auth.         | Rushville 1           | Fort Collins, CO   | 280           | M                                   | 12-83             | W. Subbit. Coal          | 0.29                               | 8.0                     | 80 Max.      | 0.9                      | 0                                  | Var.                                       |
| Sierra Pacific Power             | North Valley          | Valley, NV         | 270           | M                                   | 5-85              | W. Subbit. Coal          | 0.4                                | 11.0                    | 70           | 1.2-1.5                  | 0                                  | Var.                                       |
| Sunflower Electric Corp.         | Helicumb 1            | Helicumb, KS       | 319           | M                                   | 6-83              | WY Subbit. Coal          | 0.4                                | 8.0                     | 80           | 1.1                      | 0                                  | Var.                                       |
| Tucson Electric Power            | Springerville 1       | Springerville, AZ  | 420           | M                                   | 6-85              | MT Subbit. Coal          | 0.76                               | 13.03                   | 63           | 1.09                     | 0                                  | Var.                                       |
| United Power Assoc.              | Stanton 10            | Stanton, MO        | 60            | M                                   | 6-82              | MD Lignite               | 0.77                               | 6.9                     | 91           | 1.25                     | 0                                  | 0 <sup>d</sup>                             |
| Planned Systems                  |                       |                    |               |                                     |                   |                          |                                    |                         |              |                          |                                    |                                            |
| Cajon Electric                   | Graham 1 <sup>a</sup> | Coushatta, LA      | 563           | M                                   | None <sup>a</sup> | Louisiana Lignite        | 0.93                               | 21.1                    | 80           | M.R.                     | M.R.                               | Var.                                       |
| Central & Southwestern Services  | Calista Creek 2       | Corpus Christi, TX | 710           | M                                   | Dec. 1994         | CD Subbit. Coal          | 0.4                                | M.R.                    | 70           | M.R.                     | M.R.                               | Var.                                       |
| Northern States Power Co.        | Shawnee Co. 3         | Becker, MN         | 660           | M                                   | Jan. 1987         | Sippy Creek Subbit. Coal | 0.9                                | 10.0                    | 70           | 1.04                     | 0                                  | Var.                                       |
| Pacific Power & Light            | Wyandah 1             | Gillette, WY       | 310           | R                                   | Sep. 1986         | WY Subbit. Coal          | 0.4                                | 5                       | 75           | M.R.                     | 0                                  | Var.                                       |
| Tucson Electric Power            | Springerville 2       | Springerville, AZ  | 350           | M                                   | Jan. 1990         | MT Subbit. Coal          | 0.69                               | 20.0                    | 61           | M.R.                     | M.R.                               | Var.                                       |

Key: M - New  
R - Retrofit  
M.R. - Not Reported  
B - Baghouse  
E - Electrostatic Precipitator  
Var. - Variable Film

<sup>a</sup> Currently not recycled due to conveyor operational problems.  
<sup>b</sup> Baghouse and spray dryer were retrofitted into station at the same time.  
<sup>c</sup> Designed for 200 but currently not allowing solids to collect in spray dryer.  
<sup>d</sup> Recycle capabilities being installed.  
<sup>e</sup> Plans for Babcock 1 are on "indefinite delay."

TABLE XIII

## SUMMARY OF EXISTING UTILITY CALCIUM SPRAY DRYER WASTE MANAGEMENT SYSTEMS/19/

| STATION<br>and<br>UNIT | TRANSFER                      |             |                 |                | STORAGE            |                 |                 |                  |                     |                    |                 |                  |                |                  | CONDITIONING |                                  |                               | TRANSPORT          |       |                         | DISPOSAL         |               |                       |             |              |                       |               |                 |                |                |                    |           |          |        |       |       |            |            |            |            |            |            |            |            |            |            |            |            |            |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|------------------------|-------------------------------|-------------|-----------------|----------------|--------------------|-----------------|-----------------|------------------|---------------------|--------------------|-----------------|------------------|----------------|------------------|--------------|----------------------------------|-------------------------------|--------------------|-------|-------------------------|------------------|---------------|-----------------------|-------------|--------------|-----------------------|---------------|-----------------|----------------|----------------|--------------------|-----------|----------|--------|-------|-------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|                        | WASTES CONVEYED<br>SEPARATELY | Spray Dryer |                 | Part Collector |                    | Recycle Solids  |                 |                  | Solids for Disposal |                    |                 |                  |                |                  |              | WATER ADDED PRIOR<br>TO DISPOSAL | FINAL MOISTURE<br>CONTENT (%) | OPERATING PROBLEMS | TRUCK | BELT<br>SLURRY PIPELINE | DISTANCE (MILES) | DISPOSAL AREA | Wastes<br>Co-Disposed |             |              |                       | Liner<br>Type |                 |                |                |                    |           |          |        |       |       |            |            |            |            |            |            |            |            |            |            |            |            |            |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|                        |                               | Pneumatic   |                 | Pneumatic      |                    | Waste<br>Source | Waste<br>Source | SEPARATE STORAGE | MIXED STORAGE       | OPERATING PROBLEMS | PART. COLLECTOR | SEPARATE STORAGE | WASTE<br>DRYER | SEPARATE STORAGE | STEEL        |                                  |                               |                    |       |                         |                  |               | CONCRETE              | SILO HEATED | BOTTOM SHAPE | Flow Assist<br>Device |               |                 |                | Feeder<br>Type |                    |           |          |        |       |       |            |            |            |            |            |            |            |            |            |            |            |            |            |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|                        |                               | VACUUM      | PRESSURE-DILUTE | PRESSURE-DENSE | OPERATING PROBLEMS |                 |                 |                  |                     |                    |                 |                  |                |                  |              |                                  |                               |                    |       |                         |                  |               |                       |             |              | VACUUM                |               | PRESSURE-DILUTE | PRESSURE-DENSE |                | OPERATING PROBLEMS | FLUIDIZER | VIBRATOR | ROTARY | SCREW | OTHER |            |            |            |            |            |            |            |            |            |            |            |            |            |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|                        |                               |             |                 |                |                    |                 |                 |                  |                     |                    |                 |                  |                |                  |              |                                  |                               |                    |       |                         |                  |               |                       |             |              |                       |               |                 |                |                |                    |           |          |        |       |       | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL | MECHANICAL |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Y                      | X                             | Y           | X               | Y              | X                  | Y               | X               | Y                | X                   | Y                  | X               | Y                | X              | Y                | X            | Y                                | X                             | Y                  | X     | Y                       | X                | Y             | X                     | Y           | X            | Y                     | X             | Y               | X              | Y              | X                  | Y         | X        | Y      | X     | Y     | X          | Y          | X          | Y          | X          | Y          | X          | Y          | X          | Y          | X          | Y          | X          | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X | Y | X |

Footnotes

Y - Yes  
N - No  
NR - Not Reported  
X - Presently in Use  
F - Flat Bottom  
C - Conical Bottom

LF - Landfill  
P - Pond  
SM - Surface Mine  
L - Lined  
U - Unlined

A - Mechanical conveyor was installed initially, but was replaced with a pneumatic system  
B - Water and wet scrubber sludge added  
C - Solids are wetted at disposal site  
D - Information presented herein for Riverside Station, Units 6 & 7 was obtained from published reports  
E - Mechanical conveyor under spray dryer transfers waste to pneumatic system for transfer to recycle storage silo  
F - Mechanical conveyor under fabric filter transfers waste to pneumatic system for transfer to recycle or disposal silo  
G - Vacuum pneumatic system under fabric filter transfers waste to pressure pneumatic system for transfer to recycle  
H - Solids no longer collected in spray dryer

Table XIV

## SUMMARY OF ELEMENTAL ANALYSES ON RIVERSIDE WASTE SOLID SAMPLES/24/

| Element                | Low Sulphur<br>Coal<br>(mg/kg) | High Sulphur<br>Coal<br>(mg/kg) | High Sulfur Coal<br>With CaCl <sub>2</sub> Addition<br>(mg/kg) |
|------------------------|--------------------------------|---------------------------------|----------------------------------------------------------------|
| Aluminum               | 53,000                         | 33,000                          | 35,000 <sup>a</sup>                                            |
| Antimony <sup>c</sup>  | <20                            | <30                             | <6 <sup>b</sup>                                                |
| Arsenic <sup>c</sup>   | <20                            | <20                             | <11                                                            |
| Barium                 | 2,900                          | 260                             | 210                                                            |
| Beryllium              | 0.94 <sup>d</sup>              | 1.7 <sup>d</sup>                | 1.5 <sup>d</sup>                                               |
| Boron                  | ND <sup>d</sup>                | ND <sup>d</sup>                 | ND <sup>d</sup>                                                |
| Cadmium <sup>c</sup>   | <1                             | <1                              | 6.1                                                            |
| Calcium                | 160,000                        | 200,000                         | 180,000                                                        |
| Chromium               | 6.9                            | 54                              | 49                                                             |
| Cobalt                 | 8.9                            | 15                              | 14                                                             |
| Copper                 | 33                             | 45                              | 1.1                                                            |
| Iron                   | 23,000                         | 39,000                          | 45,000                                                         |
| Lead <sup>c</sup>      | 31                             | 48                              | 22                                                             |
| Magnesium              | 14,000                         | 4,600                           | 4,500                                                          |
| Manganese              | 638 <sup>d</sup>               | 190 <sup>d</sup>                | 200 <sup>d</sup>                                               |
| Mercury <sup>c</sup>   | ND <sup>d</sup>                | ND <sup>d</sup>                 | ND <sup>d</sup>                                                |
| Molybdenum             | 24                             | 29                              | 27                                                             |
| Nickel                 | 200                            | 50                              | 50                                                             |
| Potassium <sup>c</sup> | 7,900                          | 8,700                           | 9,300                                                          |
| Selenium <sup>c</sup>  | <30                            | <50                             | <20                                                            |
| Silicon                | 99,000                         | 70,000                          | 78,000                                                         |
| Silver                 | <0.4                           | <2                              | <0.4                                                           |
| Sodium                 | 3,400                          | 1,040                           | 3,200                                                          |
| Strontium              | 2,000                          | 170                             | 240                                                            |
| Thallium               | <30                            | <30                             | <20                                                            |
| Tin                    | <100                           | <100                            | <20                                                            |
| Titanium               | 2,900                          | 2,400                           | 2,500                                                          |
| Vandium                | 480                            | 99                              | 86                                                             |
| Zinc                   | 28                             | 210                             | 220                                                            |

<sup>a</sup> Analysis was by ICPEs on solution prepared by lithium metaborate fusion. Other elemental concentrations in solids were determined using perchloric acid solutions.

<sup>b</sup> "Less than" values indicate analytical detection limit.

<sup>c</sup> Concentrations in extracts measured by atomic absorption spectrophotometry.

<sup>d</sup> Not determined because boron and mercury are lost during digestion procedure.

Table XV

UNCONFINED COMPRESSIVE STRENGTH (UCS)  
FOR RIVERSIDE SPRAY DRYER WASTE PRODUCTS/24/

| Sample Description                          | Percent Moisture<br>Dry Basis <sup>a</sup> | Average 28-Day UCS<br>(MPa) | Average 56-Day UCS<br>(MPa) |
|---------------------------------------------|--------------------------------------------|-----------------------------|-----------------------------|
| Low Sulphur Coal                            | 20                                         | 0.3                         | 0.4                         |
|                                             | 26                                         | 0.5                         | 0.6                         |
|                                             | 32                                         | 0.8                         | 1.2                         |
| High Sulphur Coal                           | 36                                         | 0.2                         | 0.3                         |
|                                             | 42                                         | 0.3                         | 0.3                         |
|                                             | 48                                         | 0.5                         | 0.8                         |
| High Sulphur Coal<br>with CaCl <sub>2</sub> | 24                                         | 0.1                         | 0.05                        |
|                                             | 32                                         | 0.2                         | 0.15                        |
|                                             | 40                                         | 0.5                         | 0.4                         |

<sup>a</sup> Dry Basis = g H<sub>2</sub>O/100 g of dry solids

Table XVI

AVERAGE PERMEABILITY COEFFICIENTS FOR COMPACTED AND CURED  
RIVERSIDE SPRAY DRYER WASTE PRODUCTS/24/

| Sample                              | Permeability Coefficient Mean<br>Value (cm/s) <sup>a,b</sup> |
|-------------------------------------|--------------------------------------------------------------|
| Low Sulphur                         | $2.6 \times 10^{-5}$                                         |
| High Sulphur                        | $9.6 \times 10^{-7}$                                         |
| High Sulphur with CaCl <sub>2</sub> | $1.0 \times 10^{-4}$                                         |

<sup>a</sup> Average of 10 determinations

<sup>b</sup> After curing 28 days

Table XVII

RATIOS OF CONCENTRATIONS TO EP TOXICITY LIMITS IN EP EXTRACTS  
OF SPRAY DRYER WASTE PRODUCTS FROM TEST FACILITY AT RIVERSIDE  
STATION<sup>a</sup>/24/

| Element  | Low Sulphur Coal<br>(75% SO <sub>2</sub> Removal) <sup>c</sup> |         | High Sulphur Coal<br>(90% SO <sub>2</sub> Removal) <sup>c</sup> |         | with CaCl <sub>2</sub> <sup>b</sup><br>(90% SO <sub>2</sub> Removal) <sup>c</sup> |         |
|----------|----------------------------------------------------------------|---------|-----------------------------------------------------------------|---------|-----------------------------------------------------------------------------------|---------|
|          | Uncured                                                        | Cured   | Uncured                                                         | Cured   | Uncured                                                                           | Cured   |
| Arsenic  | <0.0006                                                        | <0.0006 | <0.0006                                                         | <0.0006 | <0.0006                                                                           | <0.0006 |
| Barium   | 0.012                                                          | 0.012   | 0.016                                                           | 0.010   | 0.015                                                                             | 0.009   |
| Cadmium  | <0.0005                                                        | <0.0005 | <0.0005                                                         | <0.0005 | <0.0005                                                                           | <0.0005 |
| Chromium | <0.0002                                                        | <0.0001 | 0.029                                                           | 0.008   | 0.026                                                                             | 0.011   |
| Lead     | <0.0004                                                        | <0.0004 | <0.0004                                                         | <0.0004 | <0.0004                                                                           | <0.0004 |
| Mercury  | <0.001                                                         | <0.001  | <0.001                                                          | <0.001  | <0.001                                                                            | <0.001  |
| Selenium | <0.003                                                         | <0.003  | <0.003                                                          | <0.003  | <0.003                                                                            | <0.003  |
| Silver   | <0.0004                                                        | <0.0004 | <0.0004                                                         | <0.0004 | <0.0004                                                                           | <0.0004 |

<sup>a</sup> Ratios less than 1.0 indicate the EP toxicity limits are not exceeded for that trace element. Ratios less than 0.01 indicate that maximum contaminant levels (MCLs) in public drinking water supplies are not exceeded for that trace element.

<sup>b</sup> CaCl<sub>2</sub> added to atomizer feed slurry to achieve approximately 1% Cl in the waste product.

<sup>c</sup> Cured for 28 days with optimum moisture added.

Table XVIII

EFFECTS OF CURING ON EP EXTRACTS OF RIVERSIDE WASTE SOLIDS<sup>a,b/24/</sup>

|                            | High Sulphur Coal With |                   |                            |
|----------------------------|------------------------|-------------------|----------------------------|
|                            | Low Sulphur Coal       | High Sulphur Coal | CaCl <sub>2</sub> Addition |
| Aluminum                   | +                      | +                 | nc                         |
| Antimony                   | nc                     | nc                | nc                         |
| Arsenic                    | nc                     | nc                | nc                         |
| Barium                     | nc                     | -                 | -                          |
| Beryllium                  | +                      | nc                | -                          |
| Boron                      | -                      | -                 | -                          |
| Cadmium                    | nc                     | nc                | nc                         |
| Calcium                    | -                      | nc                | -                          |
| Chromium                   | nc                     | -                 | -                          |
| Cobalt                     | nc                     | nc                | nc                         |
| Copper                     | +                      | nc                | +                          |
| Iron                       | +                      | nc                | -                          |
| Lead                       | nc                     | nc                | nc                         |
| Magnesium                  | -                      | +                 | -                          |
| Manganese                  | -                      | +                 | -                          |
| Mercury                    | nc                     | nc                | nc                         |
| Molybdenum                 | -                      | -                 | -                          |
| Nickel                     | -                      | +                 | -                          |
| Potassium                  | -                      | +                 | +                          |
| Selenium                   | nc                     | nc                | +                          |
| Silicon                    | -                      | +                 | nc                         |
| Silver                     | nc                     | nc                | nc                         |
| Sodium                     | nc                     | +                 | nc                         |
| Strontium                  | -                      | +                 | -                          |
| Thallium                   | nc                     | nc                | nc                         |
| Tin                        | nc                     | nc                | nc                         |
| Titanium                   | +                      | nc                | nc                         |
| Vanadium                   | -                      | nc                | -                          |
| Zinc                       | nc                     | +                 | -                          |
| pH Neutral/EP <sup>b</sup> | 6.5/5.0                | 11.8/5.0          | 5.5/5.0                    |

<sup>a</sup> + = concentration in extract of cured waste product higher than concentration in extract of product as collected  
 nc = concentration in two extracts the same  
 - = concentration in extract of cured waste product lower than concentration in extract of product as collected

<sup>b</sup> Curing period 28 days

<sup>c</sup> pH of EP extract of uncured sample followed by pH of EP extract of cured sample

significantly higher in the cured waste extract. Moreover, the cured sample crumbled during the standard structural integrity test. However, it was noted that the overall trend (in the extraction tests) was decidedly "toward lower concentrations in extracts of the cured products".

Waste solids from this spray dryer-based dry FGD system appeared to have acceptable landfill disposal properties, with high unconfined compressive strengths of up to 1.2 MPa, and permeability coefficients of  $\sim 10^{-5}$  cm/s in cured samples that had optimum moisture levels added. However, an additional conclusion was made about the quantity of wastes produced. If it is desired to attain optimum compacted density, maximum unconfined compressive strength, and minimum permeability coefficient, then it may be necessary to add significant quantities of water to the wastes. The results of the solid waste characterization study for this program indicated that optimum solid waste strength and permeability values were achieved at moisture levels in the three solid waste samples ranging from 32-48% (dry solids basis). In this instance, both the water consumption and the volume of wastes produced by the "dry" system would not be significantly different from those for a wet FGD system where the sludge is dewatered and subsequently blended with fly ash. If only minimum moisture to avoid dusting is added to the dry FGD wastes, the water requirements can be significantly reduced. Also, the water consumption and volume of wastes produced by the "dry" system are much smaller.

A laboratory-scale characterization of solid waste samples collected during this program indicated that the cured samples from the low sulphur coal tests and the baseline high sulphur coal tests had unconfined compressive strength values that should allow landfilling of the material. The samples from the high chloride test showed poorer values of unconfined compressive strength. These values were on the borderline of being adequate to allow landfilling. Also, the samples from the low sulphur and high sulphur baseline tests had permeability coefficients in the range of  $10^{-5}$ - $10^{-7}$  cm/s. These values are typical for FGD sludges. The permeability coefficient for the high chloride test was approximately  $10^{-4}$  cm/s, indicated that free moisture would more readily leach through a landfill of this material. These results indicate that although chloride addition was effective in reducing lime reagent consumption rates, it may have negative impacts on solid waste disposal characteristics.

#### 4.3.2 Argonne National Laboratory Spray Drying Tests

In 1981, Argonne National Laboratory (ANL) installed a retrofit lime spray dryer scrubber system for  $\text{SO}_2$  removal from its baseload boiler, burning Illinois bituminous coal containing (a) 3-3.5% w/w sulphur, and (b) 4.5% w/w sulphur/25/.

Waste from the ANL system is currently landfilled on-site. The spent sorbent is mixed at the landfill with fly ash from the coal-fired boiler. Various mixtures of fly ash and spent sorbent were subjected to the EPA EP Toxicity Test to determine the composition of the leachate produced. The results

showed correlation between the leachate composition and the waste blend (sor bent/ash), and that individual trace element concentrations are strongly influenced by pH. The tests showed the lime spray dryer wastes to be 'non-leachate toxic' in terms of the US Federal hazardous waste definition.

#### 4.4 Summary and Conclusions

Lime spray dryer wastes examined to date can probably be classified as non-hazardous and disposed of accordingly. Because of their inherent pozzolanic properties, consequent low permeability, and suitable leachate quality, landfill disposal of these wastes may be environmentally acceptable without a liner. Water in the landfill area will tend to run off rather than through the landfill, and so minimize the amount of leachate generated.

### 5.0 LIMESTONE INJECTION INTO THE FURNACE (LIF) WASTES

#### 5.1 Preliminary Studies

Ontario Hydro plans to determine and optimize the feasibility of acid gas emission control by direct injection of pulverized limestone into the furnace (LIF). It is also planned to study the effectiveness of using slaked lime and other alternative dry sorbents. Of the four candidate processes, limestone injection has the potential of being the easiest and least expensive to retrofit. Although SO<sub>2</sub> removal efficiency is relatively low (about 40-50%) for this process, there are promising signs that it can be increased.

A literature review showed that there is a paucity of information on the waste handling/disposal aspects of limestone injection wastes/26,27/. Some studies have been conducted in the USA on LIMB technology (Limestone Injection, Multistage Burners), but details regarding solid waste disposal have yet to be formulated/28/. In Canada, there is an ongoing study by Dearborn Environmental Consultants/29/ dealing with a proposed circulating fluidized bed combustion process for removal of flue gas SO<sub>2</sub> from high-sulphur coal combustion planned to take place at the Chatham Station, New Brunswick. However, this study has to date been limited to characterization of the wastes from pilot-scale tests at the University of British Columbia (UBC), and the recirculatory nature of the process yields wastes with lower CaO reactivity compared with LIF wastes (see below).

A sample of Consol limestone injection waste was obtained early in 1985 from the Dupont Inc nylon production plant at Martinsville, Virginia, USA. Consol waste was considered to be the best available substitute for LIF waste expected to be produced initially at Lakeview TGS in December, 1985. Accordingly, the Consol waste was characterized in detail, both chemically and physically/26/. Consol LIF waste contained by weight about 33.3% of free CaO, <3% of Ca(OH)<sub>2</sub>, 18.2% of CaSO<sub>4</sub>, 8% of CaCO<sub>3</sub> and 12.5% of unburnt carbon. The material reacted exochemically with water: maximum temperatures

of ~ 100°C were observed by calorimetry, and ~ 160°C under bulk slaking conditions. The heat of reaction was about -68.9 cal/g, attributed predominantly to hydration of the CaO.

Laboratory-cured mixes of Consol waste and water were found to resemble natural earth materials in their physical properties/26/. Ontario MOE Regulation 309 leaching tests/33/ were carried out on the fixated Consol waste. The results (Section 5.5 below) showed the materials to be non-hazardous, ie non-'leachate toxic'.

Since dusting was recognized to be a potential problem during handling/disposal of LIF waste, and it was uncertain whether equipment (ie, dustless unloaders) already available on-site at Lakeview TGS and other stations would provide safe, effective means of adding water, small-scale tests of slaking equipment and of pelletizing equipment were performed. Of the two, conventional slaking equipment proved unpromising/30/. A sample of Consol LIF waste was sent to Ferro-Tech, Wyandotte, Michigan, USA, and treated at their pilot-scale facility/31/. The pelletized product was dust-free and gave negligible temperature rise on wetting with water. Ferro-Tech are represented in Canada by the Steve Placek Company Ltd, Toronto, Ontario.

## 5.2 LIF Waste Characterization to December, 1986

After the preliminary characterization work was done on Consol LIF waste, a further 70 samples of other LIF waste samples, originating within Ontario Hydro was obtained, and a number of there were characterized in detail both chemically and physically. The sources of these additional samples were:

- Lakeview TGS, December, 1985. Station trials (9 samples).
- Lakeview TGS, June/July, 1986. Station trials (59 samples).
- Combustion Research Facility (CRF), Chemical Research Dept (2 samples).

Since only very small amounts of waste were available from each of the individual CRF tests, the samples received for examination were made into composites taken from different tests under identical sorbent injection conditions.

Identification of the samples of maximum interest and the conditions under which they were sampled are given in Tables XIX, XX and XXI respectively.

Further LIF trials were held at Lakeview TGS in July-September, 1987. Waste characterization is currently under way.

TABLE XIX

IDENTIFICATION OF LIF WASTE SAMPLES FROM LAKEVIEW TGS  
LIF TESTS IN DECEMBER 1985

| Sample No | Date   | Test No | Sample Time (Est) | Source Hoppers Nos | Side | Sorbent and Injection Rate (Mg/h) |                     | Load (MW) | SO <sub>2</sub> (mg/L) | CaO Content Of LIF Waste Sample (g/kg) |
|-----------|--------|---------|-------------------|--------------------|------|-----------------------------------|---------------------|-----------|------------------------|----------------------------------------|
|           |        |         |                   |                    |      | Lime-stone                        | Ca(OH) <sub>2</sub> |           |                        |                                        |
| 1         | Dec 10 | 3       | 15:45             | 14                 | B    | 13                                | 0                   | 222       | 877                    | 240                                    |
| 2         | Dec 10 | 3       | 16:00             | 11                 | A    | 13                                | 0                   | 222       | 877                    | 340                                    |
| 3         | Dec 11 | 5       | 13:00             | 11                 | A    | 12.1                              | 0                   | 220       | 842                    | 340                                    |
| 4         | Dec 11 | 5       | 13:00             | 11                 | A    | 12.1                              | 0                   | 220       | 842                    | 360                                    |
| 5         | Dec 12 | 8       | 13:00             | 14                 | B    | 10.2                              | 0                   | 219       | 866                    | 290                                    |
| 6         | Dec 12 | 8       | 13:00             | 11                 | A    | 10.2                              | 0                   | 219       | 866                    | 310                                    |
| 7         | Dec 13 | 13      | 15:15             | 11                 | A    | 0                                 | 2.6                 | 218       | 973                    | 120                                    |
| 8         | Dec 16 | -       | -                 | Truck              | #125 | -                                 | -                   | -         | -                      | 74                                     |
| 9         | Dec 16 | -       | -                 | Truck              | #126 | -                                 | -                   | -         | -                      | 60                                     |

Samples Nos 8 and 9 were taken from trucks after water addition had been made using dustless unloader (slaking still incomplete).

**TABLE XX**  
**IDENTIFICATION OF LIF WASTE SAMPLES AND TESTING CONDITIONS**  
**AT LAKEVIEW TGS IN JUNE/JULY, 1986**

| Date<br>(1986) | Test<br>No | Load<br>(MW) | SO <sub>2</sub><br>(ppm) | Sorbent<br>Injected      |                               | West<br>Side<br>Sample<br>No | CaO<br>Content<br>of<br>West Side<br>Sample<br>(g/kg) | East Side<br>Sample<br>No | CaO<br>Content<br>of<br>East Side<br>Sample<br>(G/kg) |
|----------------|------------|--------------|--------------------------|--------------------------|-------------------------------|------------------------------|-------------------------------------------------------|---------------------------|-------------------------------------------------------|
|                |            |              |                          | Lime-<br>stone<br>(Mg/h) | Ca(OH) <sub>2</sub><br>(Mg/h) |                              |                                                       |                           |                                                       |
| Jun 25         | 1          | 300          | 1523                     | 0                        | 0                             | 58                           | 28.6                                                  | 59                        | 29.7                                                  |
|                | 2          | "            | 1017                     | 20.8                     | 0                             | 37                           | 338                                                   | 38                        | 284                                                   |
| Jun 26         | 3          | "            | 1515                     | 0                        | 0                             | 30                           | 32.0                                                  | 28                        | 35.7                                                  |
|                | 4          | "            | 1041                     | 20.5                     | 0                             | 31                           | 298                                                   | 32                        | 299                                                   |
| Jun 27         | 5          | "            | 975                      | 21.0                     | 0                             | 55                           | 318                                                   | 57                        | 341                                                   |
|                | 6          | "            | 1531                     | 0                        | 0                             | 56                           | 110                                                   | 54                        | 135                                                   |
|                | 7          | "            | 1081                     | 18.3                     | 0                             |                              |                                                       |                           |                                                       |
|                | 8          | "            | 1074                     | 16.4                     | 0                             | 47                           | 359                                                   | 29                        | 222                                                   |
| Jul 2          | 1          | 300          | 1502                     | 0                        | 0                             | 50                           | 24.7                                                  | 52                        | 7.8                                                   |
|                | 2          | "            | 1021                     | 16.4                     | 0                             | 49                           | 282                                                   | 45                        | 183                                                   |
| Jul 3          | 3          | "            | 1490                     | 0                        | 0                             | 53                           | 8.5                                                   | 51                        | 8.6                                                   |
| Jul 4          | 4          | "            | 1014                     | 15.1                     | 0                             | 20                           | 100                                                   | 48                        | 284                                                   |
|                | 5          | "            | 1010                     | 17.8                     | 0                             | 19                           | 382                                                   | 46                        | 363                                                   |
| Jul 7          | 1          | 300          | 1298                     | 0                        | 0                             | 7                            | 46.2                                                  | 10                        | 42.5                                                  |
|                | 2          | "            | 955                      | 17.5                     | 0                             | 6                            | 195                                                   | 9                         | 169                                                   |
|                | 3          | "            | 828                      | 26.2                     | 0                             | 8                            | 280                                                   | 21                        | 247                                                   |
|                | 4          | "            | 1188                     | 0                        | 0                             |                              |                                                       |                           |                                                       |
| Jul 8          | 5          | "            | 1412                     | 0                        | 0                             | 12                           | 29.5                                                  | 43                        | 17.6                                                  |
|                | 6          | "            | 875                      | 11.8                     | 0                             | 11                           | 279                                                   | 15                        | 293                                                   |
|                | 7          | "            | 855                      | 11.8                     | 0                             | 13                           | 284                                                   | 14                        | 282                                                   |
|                | 8          | "            | 812                      | 11.8                     | 0                             |                              |                                                       |                           |                                                       |
|                | 9          | "            | 1296                     | 0                        | 0                             |                              |                                                       | 18                        | 283                                                   |
| Jul 9          | 10         | 220          | 1258                     | 0                        | 0                             | 44                           | 78.4                                                  | 25                        | 30.4                                                  |
|                |            |              |                          |                          |                               |                              |                                                       | 27                        | 271                                                   |
|                | 11         | "            | 756                      | 15.17                    | 0                             | 35                           | 369                                                   | 34                        | 350                                                   |
|                | 12         | "            | 710                      | 15.17                    | 0                             |                              |                                                       |                           |                                                       |
|                | 13         | "            | 705                      | 15.17                    | 0                             |                              |                                                       |                           |                                                       |
|                | 14         | "            | 699                      | 15.17                    | 0                             |                              |                                                       |                           |                                                       |
| Jul 10         | 1          | 300          | 1246                     | 0                        | 0                             | 23                           | 126                                                   | 16                        | 96.2                                                  |
|                | 2          | "            | 894                      | 20                       | 0                             |                              |                                                       | 33                        | 264                                                   |
|                |            |              |                          |                          |                               |                              |                                                       | 36                        | 284                                                   |
|                | 3          | "            | 825                      | 25                       | 0                             | 17                           | 398                                                   | 22                        | 404                                                   |
| Jul 11         | 4          | 220          | 1244                     | 0                        | 0                             |                              |                                                       |                           |                                                       |
|                | 5          | "            | 818                      | 14.8                     | 0                             | 1                            | 30                                                    | 24                        | 311                                                   |
|                | 6          | 300          | 682                      | 22                       | 0                             | 26                           | 429                                                   |                           |                                                       |
| Jul 14         | 1          | 300          | 1387                     | 0                        | 0                             | 40                           | 168                                                   | 42                        | 92.5                                                  |
|                | 2          | "            | 791                      | 0                        | 11                            |                              |                                                       |                           |                                                       |
|                | 3          | 220          | 682                      | 0                        | 11                            |                              |                                                       |                           |                                                       |
|                | 4          | "            | 655                      | 0                        | 11                            | 41                           | 342                                                   | 39                        | 321                                                   |

**Footnote:** Sampling problems were encountered, in that the CaO content of the waste did not always reflect the corresponding sorbent injection conditions reported. For instance, the waste sampled on July 8 (Test No. 9) was found to contain 283 g/kg CaO even though the sorbent injection rate was zero during the test. The most obvious explanation is hold-up in the hoppers from previous test(s). There is clearly a need for careful back-end sampling during trials when front-end conditions are being varied.

TABLE XXI

IDENTIFICATION OF COMPOSITE LIF WASTE SAMPLES FROM COMBUSTION  
RESEARCH FACILITY, CHEMICAL RESEARCH DEPARTMENT

| LIF Waste Number<br>(Composite sample) | Sorbent Injected    | Ca/S ratio | Identification of CRF Samples Combined to make up the Composite Sample | % By Weight of Composite Sample | CaO Content of Composite Sample (g/kg) |
|----------------------------------------|---------------------|------------|------------------------------------------------------------------------|---------------------------------|----------------------------------------|
| CRF-1                                  | Limestone           | 3.0        | LV 06 Aug 19/85                                                        | 18.0                            | 267*                                   |
|                                        |                     |            | LV 07 Aug 21/85                                                        | 32.2                            |                                        |
|                                        |                     |            | LV 08 Aug 23/85                                                        | 41.5                            |                                        |
|                                        |                     |            | LV 14 Sept 19/85                                                       | 8.3                             |                                        |
| CRF-2                                  | Ca(OH) <sub>2</sub> | 2.5        | LVHL-09 Sept 22/86                                                     | 14.1                            | 7.0*                                   |
|                                        |                     |            | LVHL-10 Sept 24/86                                                     | 21.3                            |                                        |
|                                        |                     |            | LVHL-16 Oct 31/86                                                      | 20.1                            |                                        |
|                                        |                     |            | LVHL-17 Nov 4/86                                                       | 23.8                            |                                        |
|                                        |                     |            | LVHL-18 Nov 7/86                                                       | 20.7                            |                                        |

\* The CaO content figures were verified by re-analysis.

#### 5.2.1 Chemical Analysis

All 70 of the LIF waste samples received as described above were analyzed for free CaO and for  $\text{Ca(OH)}_2$ . The results are given in Table XXII. Due to the large numbers of samples obtained from the June/July, 1986 LIF trial at Lakeview TGS, only those with the highest free CaO contents were selected for more extensive examination, since it was anticipated that these would represent the most problematic wastes in terms of handling/disposal. The samples chosen for detailed characterization included LIF wastes from both limestone injection tests and slaked lime injection tests.

#### 5.2.2 Physical Characterization

Physical testing included measurement of particle size distribution, calorimetry ( $\Delta H$ ), bulk exothermicity, and dry bulk density. Results of these physical tests are given in Tables XXIII to XXVI.

#### 5.2.3 MOE Leaching Tests

Leaching tests were carried out on the selected LIF wastes "as received". The Ontario MOE Regulation 309 Leachate Extraction Procedure/32/, a co-disposal aerobic method, was used predominantly throughout. Results are given in Tables XXVII and XXVIII.

Table XXVII shows that the "as received" D85#4 LIF sample was subjected to fairly extensive leaching conditions beyond those required by Regulation 309, ie, under anaerobic as well as aerobic conditions, both with and without addition of acetic acid for pH adjustment.

The leaching test results given in Table XXVIII were exclusively obtained following the Regulation 309 Procedure: this permits comparison of the Regulation 309 leaching characteristics for LIF wastes "as received", "fixated and cured" and "fixated and dried" (see below).

#### 5.2.4 LIF Waste Fixation Procedures

The selected LIF wastes were fixated by blending various ratios of water with each waste to produce a wet plaster-like consistency. It was recognized that in field disposal practice the mix could either be allowed to set slowly by placement in bulk at a designated landfill site, or else set more rapidly by placement in shallow lifts which would accelerate drying and improve local working conditions.

TABLE XXII

MAJOR CHEMICAL ANALYSIS OF LIF WASTES FROM LAKEVIEW TGS (DEC, 1985 AND  
JUN/JULY, 1986) AND THE COMBUSTION RESEARCH FACILITY  
(CHEMICAL RESEARCH DEPT, FALL, 1986)

| Sample<br>Number |    | Free CaO<br>q/kg | Ca(OH) <sub>2</sub><br>q/kg | CaCO <sub>3</sub><br>q/kg | CaSO <sub>4</sub><br>q/kg | Unburnt<br>Carbon<br>g/kg | Sulphur<br>q/kg | Carbonate<br>as CO <sub>3</sub><br>q/kg | Sulphite<br>as CaSO <sub>3</sub><br>q/kg |
|------------------|----|------------------|-----------------------------|---------------------------|---------------------------|---------------------------|-----------------|-----------------------------------------|------------------------------------------|
| D85              | 1  | 240              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 220              | <30                         | 49.1                      | 112                       | 109                       |                 |                                         |                                          |
| "                | 2  | 260              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 330              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 340              | <30                         | 48.4                      | 110                       | 85                        |                 |                                         |                                          |
| "                | 3  | 340              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 330              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 340              | <30                         | 69.1                      | 67                        | 75                        |                 |                                         |                                          |
| "                | 4  | 350              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 400              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 340              | <30                         | 69.4                      | 121                       | 69                        |                 |                                         | 6.15                                     |
| "                | 5  | 350              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 270              | <30                         | 52.5                      | 140                       | 103                       |                 |                                         |                                          |
| "                | 6  | 320              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 290              | <30                         | 54.6                      | 109                       | 83                        |                 |                                         |                                          |
| "                | 7  | 330              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 120              | <30                         | 17.5                      | 94                        | 101                       |                 |                                         | 2.10                                     |
| "                | 8  | 130              |                             |                           |                           |                           |                 |                                         |                                          |
|                  |    | 74               | 30                          | 37.5                      | 78                        | 88                        |                 |                                         |                                          |
| "                | 9  | 60               | 30                          | 36.4                      | 60                        | 87                        |                 |                                         |                                          |
| J/J86            | 59 | 30.4             | <10                         |                           |                           |                           |                 |                                         |                                          |
|                  |    | 29.0             |                             |                           |                           |                           |                 |                                         |                                          |
| "                | 58 | 28.6             | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 57 | 341              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 56 | 110              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 55 | 318              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 54 | 135              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 53 | 8.5              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 52 | 7.8              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 51 | 8.6              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 50 | 24.7             | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 49 | 282              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 48 | 285              | <10                         |                           |                           |                           |                 |                                         |                                          |
|                  |    | 283              |                             |                           |                           |                           |                 |                                         |                                          |
| "                | 47 | 359              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 46 | 363              | <10                         | 71                        | 61.9                      | 80.6                      | 14.6            | 42.8                                    |                                          |
| "                | 45 | 183              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 44 | 78.4             | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 43 | 17.6             | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 42 | 92.5             | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 41 | 341              | <10                         | 109                       | 116.4                     | 50.4                      | 27.4            | 65.1                                    |                                          |
|                  |    | 342              |                             |                           |                           |                           |                 |                                         |                                          |
| "                | 40 | 168              | <10                         |                           |                           |                           |                 |                                         |                                          |
| "                | 39 | 321              | <10                         | 83.4                      | 101.9                     | 65.4                      | 24.0            | 50.0                                    |                                          |

TABLE XXII (CONT)

MAJOR CHEMICAL ANALYSIS OF LIF WASTES FROM LAKEVIEW TGS (DEC, 1985 AND  
JUN/JULY, 1986) AND THE COMBUSTION RESEARCH FACILITY  
(CHEMICAL RESEARCH DEPT, FALL, 1986)

| Sample Name |    | Free CaO<br>g/kg | Ca(OH) <sub>2</sub><br>g/kg | CaCO <sub>3</sub><br>g/kg | CaSO <sub>4</sub><br>g/kg | Unburnt<br>Carbon<br>g/kg | Sulfur<br>g/kg | Carbonate<br>as CO <sub>3</sub><br>g/kg | Sulphite<br>as CaSO <sub>3</sub><br>g/kg |
|-------------|----|------------------|-----------------------------|---------------------------|---------------------------|---------------------------|----------------|-----------------------------------------|------------------------------------------|
| "           | 38 | 284              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 37 | 338              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 36 | 284              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 35 | 369              | <10                         | 147                       | 104.3                     | 68.9                      | 24.6           | 88.4                                    |                                          |
| "           | 34 | 350              | <10                         | 140                       | 102.1                     | 68.6                      | 24.0           | 84.2                                    |                                          |
| "           | 33 | 264              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 32 | 299              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 31 | 299              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           |    | 296              |                             |                           |                           |                           |                |                                         |                                          |
| "           | 30 | 32               | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 29 | 222              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 28 | 35.7             | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 27 | 271              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 26 | 429              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 25 | 28.7             | <10                         |                           |                           |                           |                |                                         |                                          |
| "           |    | 32.1             |                             |                           |                           |                           |                |                                         |                                          |
| "           | 24 | 311              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 23 | 126              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 22 | 404              | <10                         | 91.7                      | 70.3                      | 75.9                      | 16.6           | 55                                      |                                          |
| "           | 21 | 247              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 20 | 96.8             | <10                         |                           |                           |                           |                |                                         |                                          |
| "           |    | 104              |                             |                           |                           |                           |                |                                         |                                          |
| "           | 19 | 382              | <10                         | 77.4                      | 76.2                      | 67.2                      | 18.0           | 46.4                                    |                                          |
| "           | 18 | 283              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 17 | 398              | <10                         | 114                       | 77.5                      | 63.6                      | 18.3           | 68.3                                    |                                          |
| "           | 16 | 96.2             | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 15 | 293              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 14 | 282              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 13 | 288              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           |    | 280              |                             |                           |                           |                           |                |                                         |                                          |
| "           | 12 | 29.5             | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 11 | 279              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 10 | 42.5             | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 9  | 169              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 8  | 280              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 7  | 46.2             | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 6  | 195              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 5  | 43.2             | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 4  | 293              | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 3  | 54.6             | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 2  | 29               | <10                         |                           |                           |                           |                |                                         |                                          |
| "           | 1  | 30               | <10                         |                           |                           |                           |                |                                         |                                          |
| CRF-1       |    | 260              | <30                         | 30.5                      | 137                       | 109                       | 32.2           | 18.2                                    |                                          |
|             |    | 275              |                             |                           |                           |                           |                |                                         |                                          |
| CRF-2       |    | 7.0              | <10                         | 77.9                      | 199                       | 79.7                      | 46.9           | 46.7                                    |                                          |
|             |    |                  |                             |                           |                           |                           |                | 46.6                                    |                                          |

TABLE XXIII

CALCULATED HEATS OF REACTION OF SELECTED LIF WASTES WITH WATER

Water Equivalent of Calorimeter: 10.9 g

40 g of LIF Waste Used for Each Test

| LIF Waste Sample      | Weight of Water Added to the 40 g LIF Sample (g) | Ambient Air & Water Temperature (°C) | Temperature Projected Back to Time 0 (°C) | $\Delta H$ (cal/g) |
|-----------------------|--------------------------------------------------|--------------------------------------|-------------------------------------------|--------------------|
| D85#4                 | 10                                               | ~23°C                                | 71                                        | -83.3              |
|                       | 20                                               |                                      |                                           |                    |
|                       | 30                                               |                                      |                                           |                    |
| (Limestone sorbent)   | 35                                               |                                      |                                           |                    |
|                       | 45                                               |                                      |                                           |                    |
|                       | 60                                               |                                      |                                           |                    |
| J/J86#22              | 10                                               | ~24°C                                | 73                                        | -111.0             |
|                       | 25                                               |                                      |                                           |                    |
|                       | 30                                               |                                      |                                           |                    |
| (Limestone sorbent)   | 50                                               |                                      |                                           |                    |
|                       | 65                                               |                                      |                                           |                    |
|                       | 80                                               |                                      |                                           |                    |
| J/J86#35              | 10                                               | ~24°C                                | 68                                        | -100.0             |
|                       | 25                                               |                                      |                                           |                    |
| (Limestone sorbent)   | 50                                               |                                      |                                           |                    |
|                       | 65                                               |                                      |                                           |                    |
|                       | 80                                               |                                      |                                           |                    |
| J/J86#41              | 25                                               | ~24°C                                | 61                                        | -97.7              |
|                       | 50                                               |                                      |                                           |                    |
| (Slaked lime sorbent) | 65                                               |                                      |                                           |                    |
|                       | 80                                               |                                      |                                           |                    |
|                       |                                                  |                                      |                                           |                    |
| J/J86#46              | 10                                               | ~24.5°C                              | 65                                        | -93.2              |
|                       | 25                                               |                                      |                                           |                    |
| (Limestone sorbent)   | 50                                               |                                      |                                           |                    |
|                       | 65                                               |                                      |                                           |                    |
|                       | 80                                               |                                      |                                           |                    |
| CRF-1                 | 15                                               | ~23°C                                | 65                                        | -52.0              |
|                       | 18                                               |                                      |                                           |                    |
| (Limestone sorbent)   | 25                                               |                                      |                                           |                    |
|                       | 40                                               |                                      |                                           |                    |
|                       |                                                  |                                      |                                           |                    |
| CRF-2                 | 65                                               | ~23°C                                | 66                                        | -79.7              |
| (Slaked lime sorbent) |                                                  |                                      |                                           |                    |

(C49)

TABLE XXIV  
BULK EXOTHERMICITY STUDY OF LIF WASTES: OBSERVATIONS & DATA

| LIF Waste Sample | Weight of 2L Of Lightly Packed Waste (kg) | Maximum Temperature Observed (°C) |       |       | Volume Expansion (%) | Mid-Diameter Expansion (7 cm level) (%) | CaO Content (g/kg) | Total Time Of Test (min) | Total Volume of Water Added (L) | Average Flowrate of Water Added to Waste (mL/min) |
|------------------|-------------------------------------------|-----------------------------------|-------|-------|----------------------|-----------------------------------------|--------------------|--------------------------|---------------------------------|---------------------------------------------------|
| D85#4            | -                                         | 162.2                             | 140.5 | 110.0 | 76                   | 30                                      | 360                | 239                      | 0.93                            | 3.9                                               |
| D85#7            | -                                         | 88.9                              | 77.1  | 61.4  | -                    | -                                       | 125                | 245                      | 0.98                            | 4                                                 |
| J/J86 #46        | 2.37                                      | 163.7                             | 152.9 | 134.8 | 71                   | 22                                      | 363                | 299                      | 1.16                            | 3.9                                               |
| J/J86 #35        | 2.24                                      | 189.4                             | 170.8 | 144.8 | 53                   | 18                                      | 369                | 303                      | 1.16                            | 3.8                                               |
| J/J86 #22        | 2.35                                      | 186.5                             | 187.2 | 179.2 | 79                   | 25                                      | 404                | 318                      | 1.23                            | 3.9                                               |
| J/J86 #41        | 1.54                                      | 185.7                             | 168.2 | 119.0 | 43                   | 14                                      | 341                | 300                      | 1.14                            | 3.8                                               |

TABLE XXV

## HIAC PARTICLE SIZE ANALYSIS OF LIF WASTES

| Sample Name                                            | Percentage of total no of particles |                     |                     |                      |                    |
|--------------------------------------------------------|-------------------------------------|---------------------|---------------------|----------------------|--------------------|
|                                                        | 5-10 $\mu\text{m}$                  | 10-25 $\mu\text{m}$ | 25-50 $\mu\text{m}$ | 50-100 $\mu\text{m}$ | >100 $\mu\text{m}$ |
| D85#4*                                                 | 73.23                               | 25.00               | 1.70                | 0.12                 | 0.01               |
| D85#4-slaked*<br>10 gH <sub>2</sub> O to 40 g<br>solid | 57.20                               | 33.93               | 7.73                | 1.06                 | 0.10               |
| J/J86#41                                               | 75.9                                | 23.4                | 0.65                | 0.05                 | 0.02               |
| J/J86#46                                               | 69.2                                | 29.0                | 1.8                 | 0.01                 | 0                  |
| J/J86#35                                               | 79.7                                | 19.1                | 1.1                 | 0.13                 | 0                  |
| J/J86#22                                               | 71.3                                | 26.8                | 1.8                 | 0.12                 | 0                  |
| CRF-1                                                  | 77.9                                | 21.1                | 0.94                | 0.08                 | 0.04               |
| " -repeat                                              | 77.3                                | 21.5                | 1.1                 | 0.10                 | 0.02               |
| CRF-2                                                  | 72.49                               | 26.14               | 1.12                | 0.23                 | 0                  |
| " -repeat                                              | 73.46                               | 25.88               | 0.57                | 0.09                 | 0                  |

\* For D85#4, both the "as received" and slaked LIF waste samples were subjected to particle size determination

TABLE XXVI  
BULK DENSITY MEASUREMENTS OF LIF WASTES

| Sample                                    | Bulk Density - Average (g/mL)<br>(number of tests in brackets) |                               |                                |
|-------------------------------------------|----------------------------------------------------------------|-------------------------------|--------------------------------|
|                                           | Initial                                                        | After Tamping<br>for 1 minute | After Tamping<br>for 5 minutes |
| LVTGS Fresh Hopper<br>Flyash - Sept 23/85 | 0.69 (4)                                                       | 0.88 (4)                      | 1.08 (4)                       |
| D85#4                                     | 0.74 (10)                                                      | 1.00 (10)                     | 1.13 (10)                      |
| J/J86#22                                  | 0.80 (2)                                                       | 1.07 (2)                      | 1.23 (2)                       |
| J/J86#35                                  | 0.73 (2)                                                       | 0.97 (2)                      | 1.18 (2)                       |
| J/J86#46                                  | 0.82 (2)                                                       | 1.09 (2)                      | 1.19 (2)                       |
| J/J86#41                                  | 0.51 (2)                                                       | 0.67 (2)                      | 0.85 (2)                       |
| CRF-1                                     | 0.43 (1)                                                       | 0.57 (1)                      | 0.77 (1)                       |
| CRF-2                                     | 0.35 (1)                                                       | 0.47 (1)                      | 0.63 (1)                       |

TABLE XXVII

## MOE LEACHATE EXTRACTION: ANALYTICAL RESULTS/2,3/

LAKEVIEW TGS LIF WASTE - DEC 85 SAMPLE #4, "AS RECEIVED" CONDITION

| Parameter                                                                      | Monofill |          | Co-Disposal |          | Backfill Use:<br>Maximum Acceptable<br>Extract Concentration<br>(Monofill Test)<br>/1,2,3/ | Hazardous Waste<br>Categorization:<br>Maximum Extract<br>Concentration<br>For Exemption<br>/1,2/ |
|--------------------------------------------------------------------------------|----------|----------|-------------|----------|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
|                                                                                | Aerobic  | Anerobic | Aerobic     | Anerobic |                                                                                            |                                                                                                  |
| pH                                                                             | 12.2     | 12.8     | 12.8        | 12.8     | -                                                                                          | -                                                                                                |
| Specific Conductivity                                                          | 900      | 920      | NA          | NA       | -                                                                                          | -                                                                                                |
| As                                                                             | <0.001   | <0.001   | <0.001      | <0.001   | 0.05                                                                                       | 5                                                                                                |
| Ba                                                                             | <1       | <1       | <1          | <1       | 1.0                                                                                        | 100                                                                                              |
| B                                                                              | 4.08     | 4.00     | 4.00        | 3.82     | 5.0                                                                                        | 500                                                                                              |
| Cd                                                                             | <0.0001  | 0.0002   | <0.0001     | <0.0001  | 0.005                                                                                      | 0.5                                                                                              |
| Cr (total)†                                                                    | 0.12     | 0.12     | 0.13        | 0.13     | 0.05                                                                                       | 5                                                                                                |
| 'WAD' (CN)                                                                     | <0.04    | <0.04    | <0.04       | <0.04    | 0.2                                                                                        | 20                                                                                               |
| F                                                                              | 1.25     | 1.15     | 1.60        | 1.60     | 2.4                                                                                        | 240                                                                                              |
| Pb                                                                             | <0.0002  | <0.0002  | <0.0002     | <0.0002  | 0.05                                                                                       | 5                                                                                                |
| Hg                                                                             | <0.0002  | <0.0002  | <0.0002     | <0.0002  | 0.0001                                                                                     | 0.1                                                                                              |
| NO <sub>3</sub> (as N)                                                         | 0.05     | 0.05     | 0.05        | 0.05     | 10.0                                                                                       | 1000                                                                                             |
| NO <sub>2</sub> (as N)                                                         | 0.0003   | <0.003   | 0.003       | 0.003    | 1.0                                                                                        | 100                                                                                              |
| Total [NO <sub>3</sub> <sup>-</sup> + NO <sub>2</sub> <sup>-</sup> ]<br>(as N) | 0.05     | 0.05     | 0.05        | 0.05     | 10.0                                                                                       | 1000                                                                                             |
| U†                                                                             | <0.01    | <0.01    | <0.02       | <0.02    | 0.02                                                                                       | 2                                                                                                |
| PCBs                                                                           | <0.001   | <0.001   | <0.001      | 0.0016   | 0.003                                                                                      | 0.3                                                                                              |
| Ra-226 (pCi/L)                                                                 | 0.85     | 2.10     | 9.20        | 3.10     | 3.0 pCi/L                                                                                  | 300 pCi/L                                                                                        |
| Se                                                                             | 0.013    | 0.016    | 0.018       | 0.017    | 0.01                                                                                       | 1                                                                                                |
| Ag                                                                             | <0.0002  | <0.0002  | <0.0002     | <0.0002  | 0.05                                                                                       | 5                                                                                                |
| Cl <sup>-</sup>                                                                | 52       | 52       | 47          | 49       | 1250                                                                                       | -                                                                                                |
| Cu                                                                             | 0.002    | 0.003    | 0.005       | 0.002    | 5.0                                                                                        | -                                                                                                |
| Fe                                                                             | <0.05    | <0.05    | <0.05       | <0.05    | 1.5                                                                                        | -                                                                                                |
| Mn                                                                             | <0.02    | <0.02    | <0.02       | <0.02    | 0.25                                                                                       | -                                                                                                |
| Organic N                                                                      | 0.08     | 0.08     | 0.11        | 0.15     | 0.75                                                                                       | -                                                                                                |
| Phenols                                                                        | <0.001   | 0.004    | 0.004       | 0.006    | 0.01                                                                                       | -                                                                                                |
| SO <sub>4</sub>                                                                | 1457     | 1436     | 1410        | 1327     | 2500                                                                                       | -                                                                                                |
| TDS                                                                            | 3734     | 3760     | NA          | NA       | 2500                                                                                       | -                                                                                                |
| TOC                                                                            | <1       | <1       | NA          | NA       | 25                                                                                         | -                                                                                                |
| Zn                                                                             | <0.02    | <0.02    | <0.02       | <0.02    | 25                                                                                         | -                                                                                                |
| Ca                                                                             | 1550     | 1590     | 2990        | 3000     | -                                                                                          | -                                                                                                |
| Mg                                                                             | 0.02     | 0.02     | 0.02        | 0.02     |                                                                                            |                                                                                                  |
| Na                                                                             | 1.14     | 1.11     | 1.08        | 1.06     |                                                                                            |                                                                                                  |
| K                                                                              | 2.20     | 2.20     | 2.10        | 2.00     |                                                                                            |                                                                                                  |
| Br                                                                             | 1.3      | 1.4      | 1.2         | 1.4      |                                                                                            |                                                                                                  |
| I                                                                              | 0.19     | 0.21     | 0.18        | 0.23     |                                                                                            |                                                                                                  |
| Ti                                                                             | <0.5     | <0.5     | <1          | <1       |                                                                                            |                                                                                                  |
| V                                                                              | <0.01    | <0.01    | <0.01       | <0.01    |                                                                                            |                                                                                                  |
| NH <sub>3</sub>                                                                | <0.01    | <0.01    | <0.01       | <0.01    |                                                                                            |                                                                                                  |

† Analytical interference due to high background Ca concentrations

NA Denotes not applicable due to acetic acid addition in co-disposal tests

TABLE XXVIII

MOE LEACHATE EXTRACTION-ANALYTICAL RESULTS FOR LIF WASTES "AS RECEIVED"  
AND FIXATED - REGULATION 309/2/\*  
CO-DISPOSAL - AEROBIC

| Parameter                                                                   | D85#4       |                     |                     | J/J86#46    |                     |                     | J/J86<br>#19 | J/J86#35    |                     |                     | Hazardous Waste Categorization:<br>Maximum Extract Concentration<br>For Exemption (Co-Disposal Test)/2,3/ |
|-----------------------------------------------------------------------------|-------------|---------------------|---------------------|-------------|---------------------|---------------------|--------------|-------------|---------------------|---------------------|-----------------------------------------------------------------------------------------------------------|
|                                                                             | As<br>Rec'd | Fixed<br>&<br>Cured | Fixed<br>&<br>Dried | As<br>Rec'd | Fixed<br>&<br>Cured | Fixed<br>&<br>Dried | As<br>Rec'd  | As<br>Rec'd | Fixed<br>&<br>Cured | Fixed<br>&<br>Dried |                                                                                                           |
| pH                                                                          | 12.8        | 12.4                | 12.3                | 12.4        | 12.3                | 12.4                | 12.3         | 12.4        | 12.3                | 12.5                | -                                                                                                         |
| As                                                                          | <0.001      | 0.0014              | 0.004               | <0.001      | <0.001              | <0.001              | <0.001       | <0.001      | <0.001              | 0.001               | 5                                                                                                         |
| Ba                                                                          | <0.001      | <0.001              | <0.001              | <0.001      | <0.001              | <0.001              | <0.001       | <0.001      | <0.001              | <0.001              | 100                                                                                                       |
| B                                                                           | 4.00        | 0.2                 | 1.1                 | 3.79        | 0.1                 | 0.9                 | 4.33         | 4.93        | 0.2                 | 0.93                | 500                                                                                                       |
| Cd                                                                          | <0.0001     | <0.0005             | <0.0001             | <0.0005     | <0.0002             | <0.0001             | <0.0005      | <0.0005     | <0.0005             | <0.0001             | 0.5                                                                                                       |
| Cr (total)†                                                                 | 0.13        | <0.1                | <0.1                | 0.094       | <0.1                | <0.1                | 0.110        | 0.120       | <0.1                | <0.1                | 5                                                                                                         |
| WAD* (CN)                                                                   | <0.04       | <0.04               | <0.04               | <0.04       | <0.04               | <0.04               | <0.04        | <0.04       | <0.04               | <0.04               | 20                                                                                                        |
| F                                                                           | 1.60        | 2.2                 | 1.6                 | 2.3         | 2.2                 | 1.2                 | 2.4          | 2.9         | 2.0                 | 1.4                 | 240                                                                                                       |
| Pb                                                                          | <0.002      | <0.010              | <0.005              | <0.010      | <0.002              | <0.005              | <0.010       | <0.010      | <0.010              | <0.005              | 5                                                                                                         |
| Hg                                                                          | <0.0002     | 0.0002              | <0.0002             | <0.0002     | 0.0002              | <0.0002             | <0.0002      | <0.0002     | 0.0002              | 0.00095             | 0.1                                                                                                       |
| NO <sub>3</sub> (as N)                                                      | 0.05        | 0.02                | 0.08                | <0.23       | 0.12                | 0.06                | <0.23        | 0.23        | 0.02                | 0.10                | 1000                                                                                                      |
| NO <sub>2</sub> (as N)                                                      | 0.003       | 0.01                | 0.02                | 0.01        | 0.21                | 0.01                | 0.01         | 0.01        | 0.01                | 0.01                | 100                                                                                                       |
| Total [NO <sub>3</sub> <sup>-</sup> + NO <sub>2</sub> <sup>-</sup> ] (as N) | 0.05        | 0.03                | <0.10               | -           | 0.33                | 0.07                | -            | 0.24        | 0.03                | 0.11                | 1000                                                                                                      |
| U†                                                                          | <0.02       | <0.04               | <0.02               | <0.05       | <0.02               | <0.02               | <0.05        | <0.05       | <0.02               | <0.02               | 2                                                                                                         |
| PCBs                                                                        | <0.001      | <0.001              | <0.001              | <0.001      | <0.001              | <0.001              | <0.001       | <0.001      | <0.001              | <0.001              | 0.3                                                                                                       |
| Ba-226                                                                      | 9.20        | 3.3                 | 6.2                 | 15          | 1.7                 | 12                  | 17           | 12          | 2.7                 | 15                  | 300 pCi/L                                                                                                 |
| Se                                                                          | 0.018       | 0.0048              | 0.008               | 0.015       | 0.003               | 0.009               | 0.011        | 0.010       | 0.0041              | 0.006               | 1                                                                                                         |
| Ag                                                                          | <0.0002     | <0.001              | <0.0005             | <0.0005     | <0.0005             | <0.0005             | <0.0005      | <0.0005     | <0.001              | <0.0005             | 5                                                                                                         |
| Cl <sup>-</sup>                                                             | 47          | 31                  | 43                  | 33          | 31                  | 28.3                | 40           | 70          | 53                  | 50                  | -                                                                                                         |
| Cu                                                                          | 0.005       | 0.002               | <0.1                | <0.05       | <0.05               | <0.1                | 0.002        | 0.002       | 0.002               | <0.1                | -                                                                                                         |
| Fe                                                                          | <0.05       | <0.1                | <0.2                | <0.05       | <0.2                | <0.2                | <0.2         | <0.2        | <0.1                | <0.2                | -                                                                                                         |
| Mn                                                                          | <0.02       | <0.05               | <0.1                | <0.1        | <0.05               | <0.1                | <0.1         | <0.1        | <0.05               | <0.1                | -                                                                                                         |
| Organic N                                                                   | 0.11        | <0.1                | <0.1                | 0.27        | <0.1                | <0.1                | 0.35         | 0.24        | <0.1                | <0.1                | -                                                                                                         |
| Phenols                                                                     | 0.004       | -                   | 0.008               | <0.001      | <0.001              | 0.001               | 0.001        | 0.004       | 0.008               | <0.001              | -                                                                                                         |
| SO <sub>4</sub> <sup>-</sup>                                                | 1410        | 1400                | 1000                | 1451        | 667                 | 1400                | 1482         | 1333        | 1000                | 1140                | -                                                                                                         |
| Zn                                                                          | <0.02       | <0.05               | <0.05               | <0.05       | <0.02               | <0.05               | <0.05        | <0.05       | <0.05               | <0.05               | -                                                                                                         |
| NH <sub>3</sub>                                                             | <0.01       | 0.03                | 0.026               | -           | 0.04                | 0.015               | -            | -           | 0.05                | 0.033               | -                                                                                                         |

\* All concentrations given in mg/L except Ba-226, given in pCi/L

† Analytical interference due to high background Ca concentrations

TABLE XXVIII (Cont'd)

MOE LEACHATE EXTRACTION-ANALYTICAL RESULTS FOR LIF WASTES "AS RECEIVED"  
AND FIXATED-REGULATION 309/2/\*  
CO-DISPOSAL - AEROBIC

| Parameter                                         | J/J86 #36   |             |             | J/J86 #22   |                     |                     | J/J86 #17   |             |             | J/J86 #41           |                     |                     | Hazardous Waste Categorization:<br>Maximum Extract Concentration<br>For Exemption (Co-Disposal Test)/2,3/ |
|---------------------------------------------------|-------------|-------------|-------------|-------------|---------------------|---------------------|-------------|-------------|-------------|---------------------|---------------------|---------------------|-----------------------------------------------------------------------------------------------------------|
|                                                   | As<br>Rec'd | As<br>Rec'd | As<br>Rec'd | As<br>Rec'd | Fixed<br>&<br>Cured | Fixed<br>&<br>Dried | As<br>Rec'd | As<br>Rec'd | As<br>Rec'd | Fixed<br>&<br>Cured | Fixed<br>&<br>Dried | Fixed<br>&<br>Dried |                                                                                                           |
| pH                                                | 12.4        | 12.4        | 12.4        | 12.4        | 12.3                | 12.5                | 12.4        | 12.4        | 12.4        | 12.3                | 12.3                | 12.3                | -                                                                                                         |
| As                                                | <0.001      | <0.001      | <0.001      | <0.001      | <0.001              | <0.001              | <0.001      | <0.001      | <0.001      | <0.001              | <0.001              | <0.001              | 5                                                                                                         |
| Ba                                                | <3          | <3          | <3          | <3          | <2                  | <1                  | <3          | <3          | <3          | <2                  | <1                  | <1                  | 100                                                                                                       |
| B                                                 | 5.4         | 3.27        | 0.1         | 0.5         | 0.1                 | 0.5                 | 3.35        | 2.75        | 2.75        | 0.13                | 0.13                | 0.13                | 500                                                                                                       |
| Cd                                                | <0.0005     | <0.0005     | <0.0005     | <0.0005     | <0.0005             | <0.0001             | <0.0005     | <0.0001     | <0.0001     | <0.0002             | <0.0001             | <0.0001             | 0.5                                                                                                       |
| Cr (total)†                                       | 0.120       | 0.100       | <0.1        | <0.1        | <0.1                | <0.1                | 0.095       | 0.110       | 0.110       | <0.1                | <0.1                | <0.1                | 5                                                                                                         |
| *MAD† (CN)                                        | <0.04       | <0.04       | <0.04       | <0.04       | <0.04               | <0.04               | <0.04       | <0.04       | <0.04       | <0.04               | <0.04               | <0.04               | 20                                                                                                        |
| F                                                 | 1.5         | 1.1         | 2.3         | 1.3         | 1.3                 | 1.3                 | 0.8         | 2.3         | 2.3         | 3.5                 | 1.7                 | 1.7                 | 240                                                                                                       |
| Pb                                                | <0.010      | 0.010       | <0.010      | <0.010      | <0.010              | <0.010              | <0.010      | <0.010      | <0.010      | <0.010              | <0.010              | <0.010              | 5                                                                                                         |
| Hg                                                | <0.0002     | <0.0002     | 0.0002      | 0.0002      | 0.0002              | 0.00028             | <0.0002     | <0.0002     | <0.0002     | 0.0003              | <0.0002             | <0.0002             | 0.1                                                                                                       |
| NO <sub>3</sub> (as N)                            | <0.23       | <0.23       | 0.17        | <0.07       | <0.07               | 0.01                | <0.23       | <0.23       | <0.23       | 0.01                | 0.01                | 0.01                | 1000                                                                                                      |
| NO <sub>2</sub> (as N)                            | 0.01        | 0.01        | 0.30        | 0.01        | 0.30                | 0.01                | 0.01        | 0.02        | 0.02        | 0.02                | <0.003              | <0.003              | 100                                                                                                       |
| Total [NO <sub>3</sub> + NO <sub>2</sub> ] (as N) | -           | -           | 0.47        | 0.08        | 0.47                | 0.08                | 0.24        | -           | 0.03        | 0.03                | -                   | -                   | 1000                                                                                                      |
| UT                                                | <0.05       | <0.05       | <0.04       | <0.02       | <0.04               | <0.02               | <0.05       | <0.05       | <0.05       | <0.02               | <0.02               | <0.02               | 2                                                                                                         |
| PCBs                                              | <0.001      | <0.001      | <0.001      | <0.001      | <0.001              | <0.001              | <0.001      | <0.001      | <0.001      | <0.001              | <0.001              | <0.001              | 0.3                                                                                                       |
| Ra-226                                            | 14          | 19          | 3.4         | 12          | 3.4                 | 12                  | 15          | 14          | 14          | 2.3                 | 5.1                 | 5.1                 | 300 pCi/L                                                                                                 |
| Se                                                | 0.018       | 0.0048      | 0.008       | 0.015       | 0.008               | 0.015               | 0.003       | 0.009       | 0.009       | 0.011               | 0.010               | 0.010               | 1                                                                                                         |
| Ag                                                | <0.0002     | <0.001      | <0.0005     | <0.0005     | <0.0005             | <0.0005             | <0.0005     | <0.0005     | <0.0005     | <0.0005             | <0.0005             | <0.0005             | 5                                                                                                         |
| Cl <sup>-</sup>                                   | 60          | 51          | 37          | 44.5        | 37                  | 44.5                | 65          | 54          | 54          | 52                  | 38                  | 38                  | -                                                                                                         |
| Cu                                                | 0.005       | 0.005       | 0.003       | <0.1        | 0.003               | <0.1                | <0.001      | <0.001      | <0.001      | <0.05               | <0.1                | <0.1                | -                                                                                                         |
| Fe                                                | <0.2        | <0.2        | <0.1        | <0.2        | <0.1                | <0.2                | <0.2        | <0.2        | <0.2        | <0.05               | <0.2                | <0.2                | -                                                                                                         |
| Mn                                                | <0.1        | <0.1        | <0.05       | <0.1        | <0.05               | <0.1                | <0.1        | <0.1        | <0.1        | <0.05               | <0.1                | <0.1                | -                                                                                                         |
| Organic N                                         | 0.27        | 0.24        | <0.1        | 0.14        | <0.1                | 0.14                | 0.25        | 0.28        | 0.28        | <0.1                | <0.1                | <0.1                | -                                                                                                         |
| Phenols                                           | 0.005       | 0.004       | 0.004       | <0.001      | 0.004               | <0.001              | 0.002       | 0.002       | 0.002       | <0.001              | 0.008               | 0.008               | -                                                                                                         |
| SO <sub>4</sub> <sup>-</sup>                      | 1531        | 1378        | 1000        | 1410        | 1000                | 1410                | 1266        | 1460        | 1460        | 940                 | 1090                | 1090                | -                                                                                                         |
| Zn                                                | <0.05       | <0.05       | <0.05       | <0.05       | <0.05               | <0.05               | <0.05       | <0.05       | <0.05       | <0.02               | <0.02               | <0.02               | -                                                                                                         |
| NH <sub>3</sub>                                   | -           | -           | 0.03        | 0.014       | 0.03                | 0.014               | -           | -           | -           | 0.06                | 0.026               | 0.026               | -                                                                                                         |

\* All concentrations given in mg/L except Ra-226, given in pCi/L

† Analytical interference due to high background Ca concentrations

TABLE XXVIII (cont'd)  
MOE LEACHATE EXTRACTION-ANALYTICAL RESULTS FOR LIF WASTES "AS RECEIVED"  
AND FIXATED - REGULATION 309/2/\*  
CO-DISPOSAL - AEROBIC

| Parameter                                                                   | J/J86 #39   |             | CRF-1       |                     | CRF-2       |                     | CONSOL**    |                     | Hazardous Waste Categorization:<br>Maximum Extract Concentration<br>For Exemption (Co-Disposal Test)/2.3/ |
|-----------------------------------------------------------------------------|-------------|-------------|-------------|---------------------|-------------|---------------------|-------------|---------------------|-----------------------------------------------------------------------------------------------------------|
|                                                                             | As<br>Rec'd | As<br>Rec'd | As<br>Rec'd | Fixed<br>&<br>Cured | As<br>Rec'd | Fixed<br>&<br>Cured | As<br>Rec'd | Fixed<br>&<br>Cured |                                                                                                           |
| pH                                                                          | 12.3        | 12.4        | 12.4        | 12.4                | 12.3        | 12.2                | 12.5        | 12.4                | -                                                                                                         |
| As                                                                          | <0.001      | 0.0129      | 0.0014      | <2                  | 0.0021      | 0.0043              | <0.001      | <0.001              | 5                                                                                                         |
| As                                                                          | <3          | <2          | <2          | <2                  | <2          | <2                  | 1.1         | <1.0                | 100                                                                                                       |
| B                                                                           | 3.54        | 2.25        | 0.05        | 0.05                | 2.0         | 0.1                 | 5.6         | 0.09                | 500                                                                                                       |
| Cd                                                                          | <0.0005     | <0.0005     | <0.0005     | <0.0005             | <0.0001     | <0.0002             | <0.0001     | <0.0002             | 0.5                                                                                                       |
| Cr (total)†                                                                 | 0.120       | <0.1        | <0.1        | <0.1                | 0.3         | <0.1                | <0.1        | 0.1                 | 5                                                                                                         |
| *WAD* (CN)                                                                  | <0.04       | <0.04       | <0.04       | <0.04               | <0.04       | <0.04               | <0.05       | <0.04               | 20                                                                                                        |
| F                                                                           | 2.2         | 1.7         | 1.2         | 1.2                 | 0.98        | 1.3                 | 0.98        | 0.9                 | 240                                                                                                       |
| Pb                                                                          | <0.010      | <0.010      | <0.010      | <0.010              | <0.005      | <0.002              | <0.002      | <0.004              | 5                                                                                                         |
| Hg                                                                          | <0.0002     | 0.0007      | 0.0006      | 0.0006              | 0.0002      | <0.0002             | <0.0002     | 0.0005              | 0.1                                                                                                       |
| NO <sub>3</sub> (as N)                                                      | <0.23       | 0.11        | 0.02        | 0.02                | 0.24        | 0.08                | 0.17        | 0.031               | 1000                                                                                                      |
| NO <sub>2</sub> (as N)                                                      | 0.01        | 0.18        | 0.03        | 0.03                | 0.14        | 0.05                | 0.03        | 0.019               | 100                                                                                                       |
| Total [NO <sub>3</sub> <sup>-</sup> + NO <sub>2</sub> <sup>-</sup> ] (as N) | -           | 0.29        | 0.15        | 0.15                | 0.38        | 0.13                | 0.20        | 0.050               | 1000                                                                                                      |
| UF                                                                          | <0.05       | <0.04       | <0.02       | <0.02               | <0.02       | <0.02               | 0.03        | <0.05               | 2                                                                                                         |
| PCBs                                                                        | <0.001      | <0.001      | <0.001      | <0.001              | <0.001      | <0.001              | 0.006       | <0.002              | 0.3                                                                                                       |
| As-226                                                                      | 12          | 1.3         | 1.2         | 1.2                 | 0.5         | 0.5                 | 0.6         | 0.7                 | 300 pCi/L                                                                                                 |
| Se                                                                          | 0.010       | 0.0163      | 0.0117      | 0.0117              | 0.0196      | 0.0091              | 0.013       | <0.001              | 1                                                                                                         |
| Ag                                                                          | <0.0005     | <0.001      | <0.001      | <0.001              | <0.0005     | <0.0005             | <0.0002     | 0.0031              | 5                                                                                                         |
| Cl <sup>-</sup>                                                             | 49          | 22          | 24          | 24                  | 90          | 75                  | 136         | 146                 | -                                                                                                         |
| Cu                                                                          | 0.002       | <0.1        | <0.1        | <0.1                | <0.1        | <0.05               | 0.07        | <0.010              | -                                                                                                         |
| Fe                                                                          | <0.2        | <0.1        | <0.1        | <0.1                | <0.1        | <0.05               | <0.5        | <0.1                | -                                                                                                         |
| Mn                                                                          | <0.1        | <0.05       | <0.05       | <0.05               | <0.05       | <0.05               | <0.05       | <0.05               | -                                                                                                         |
| Organic N                                                                   | 0.38        | <0.1        | <0.1        | <0.1                | <0.1        | <0.1                | <0.06       | <0.006              | -                                                                                                         |
| Phenols                                                                     | 0.003       | 0.007       | <0.001      | <0.001              | 0.001       | <0.001              | <0.001      | 0.001               | -                                                                                                         |
| SO <sub>4</sub> <sup>-</sup>                                                | 1394        | 1407        | 814         | 814                 | 1496        | 1200                | 1290        | 1540                | -                                                                                                         |
| Zn                                                                          | <0.05       | <0.05       | <0.05       | <0.05               | <0.05       | <0.02               | 0.02        | <0.05               | -                                                                                                         |
| NH <sub>3</sub>                                                             | -           | 0.59        | 0.55        | 0.55                | -           | 0.317               | -           | -                   | -                                                                                                         |

\* All concentrations given in mg/L except As-226, given in pCi/L  
† Analytical interference due to high background Ca concentrations  
\*\* Consol waste results from previous report/1/

Accordingly, for each LIF waste two tests were done:

- a) The water/LIF waste mixture was placed in a 100% humidity room at 23°C, and allowed to cure for 7 days. This sample was labelled "Fixated and Cured" (abbreviation: FC).
- b) The water/LIF waste mixture was placed in aluminum trays in shallow layers and allowed to air dry in the open laboratory (24 to 25°C) for 4 days. This sample was labelled "Fixated & Dried" (abbreviation: FD).

Both kinds of fixated LIF wastes were then subjected to the MOE Regulation 309 Leachate Extraction Procedure in the same manner as the "As Received" wastes. The analyses of the resulting leachates are listed in Table XXVIII together with the results of the "As Received" leachate analyses.

Conditions of the fixation tests, including the water-to-LIF waste ratios and moisture content of the fixated wastes, are detailed in Table XXIX.

Determination of an exact optimum amount of water to mix with the LIF wastes for easy handling was difficult to pinpoint. The weight ratios indicated in Table XXIX represent the best practical estimate. Table XXX briefly summarizes handling characteristics of the products obtained after tests at various water-to-LIF waste ratios.

#### 5.2.5 Engineering/Physical Testing of Fixated LIF Wastes

To measure the handling characteristics and suitability of fixated LIF waste for landfill, the selected LIF wastes were submitted to appropriate engineering and physical tests.

The following LIF waste-to-water ratios were used to fixate the wastes prior to the engineering tests.

| <u>Sample Number</u> | <u>LIF Waste-to-Water Ratio</u> |
|----------------------|---------------------------------|
| D85#4                | 1:1                             |
| J/J86#22             | 1:1.2                           |
| J/J86#35             | 1:1.2                           |
| J/J86#41             | 1:1.4                           |
| J/J86#46             | 1:1                             |
| CRF-1                | 1:1.2                           |

Details of the engineering test results have previously been reported/27/. A brief summary is given in Table XXXI.

TABLE XXIX

## LIF WASTE FIXATION TESTS

## CONDITIONS OF FIXATION AND MOISTURE ANALYSIS OF FIXATED PRODUCT

| LIF<br>Waste<br>Sample | Sample to Tap<br>Water Ratio |                     | Curing Time<br>at 23°C in 100%<br>Humidity Room<br>(days) | Drying Time<br>in Air at 24°C<br>(days) | Moisture Content<br>Of Fixated Sample<br>(g H <sub>2</sub> O/kg Sample) |
|------------------------|------------------------------|---------------------|-----------------------------------------------------------|-----------------------------------------|-------------------------------------------------------------------------|
|                        | LIF<br>Sample<br>(g)         | Tap<br>Water<br>(g) |                                                           |                                         |                                                                         |
| D85#4                  | 1 (40)                       | 0.88 (35)           | 7                                                         | -                                       | 386                                                                     |
| -FC                    | 1 (40)                       | 0.88 (35)           | -                                                         | 4                                       | 2                                                                       |
| -FD                    |                              |                     |                                                           |                                         |                                                                         |
| J/J86#46               | 1 (40)                       | 1 (40)              | 7                                                         | -                                       | 412                                                                     |
| -FC                    | 1 (40)                       | 1 (40)              | -                                                         | 4                                       | 3                                                                       |
| -FD                    |                              |                     |                                                           |                                         |                                                                         |
| J/J86#35               | 1 (40)                       | 1.12 (45)           | 7                                                         | -                                       | 477                                                                     |
| -FC                    | 1 (40)                       | 1.12 (45)           | -                                                         | 4                                       | 8                                                                       |
| -FD                    |                              |                     |                                                           |                                         |                                                                         |
| J/J86#22               | 1 (40)                       | 1 (40)              | 7                                                         | -                                       | 402                                                                     |
| -FC                    | 1 (40)                       | 1 (40)              | -                                                         | 4                                       | 6                                                                       |
| -FD                    |                              |                     |                                                           |                                         |                                                                         |
| J/J86#41               | 1 (40)                       | 1.38 (55)           | 7                                                         | -                                       | 526                                                                     |
| -FC                    | 1 (40)                       | 1.38 (55)           | -                                                         | 4                                       | 78                                                                      |
| -FD                    |                              |                     |                                                           |                                         |                                                                         |
| CRF-1                  | 1 (40)                       | 1.38 (55)           | 7                                                         | -                                       | 521                                                                     |
| -FC                    |                              |                     |                                                           |                                         |                                                                         |
| CRF-2                  | 1 (40)                       | 1.25 (50)           | 7                                                         | -                                       | 472                                                                     |
| -FC                    |                              |                     |                                                           |                                         |                                                                         |

TABLE XXX

DESCRIPTION OF SLAKED PRODUCTS OBTAINED FROM COMBINING VARIOUS RATIOS OF LIF WASTE AND WATER IN CALORIMETRY TESTS

| LIF Waste Sample | LIF: Water Ratio (Weight Basis) | Ambient & Water Temperature (°C) | Description of LIF Waste/Water Mixture After Calorimetry Test Completed                                                                                                                           |
|------------------|---------------------------------|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| J/J86 #46        | 40:10                           | 25                               | -Mixture of dry powder & dry set material which had to be broken up to remove from the calorimeter: a dry mixture of lumpy/powdery material.                                                      |
|                  | 40:25                           | 24.1                             | -Damp-to-dry mixture of powder & lumps and some damp semi-set material which had to be chipped out of calorimeter: a mixture of damp to dry powder and lumps of light to moderately set material. |
|                  | 40:50                           | 24.7                             | -stiff wet sandy plaster: a thin film of excess water squeezed out when material handled.                                                                                                         |
|                  | 40:65                           | 24.7                             | -wet sandy plaster which separated out into a solid phase with a small superatant aqueous layer.                                                                                                  |
|                  | 40:80                           | 25                               | -watery slurry, settled out into a solid layer with a superatant aqueous layer.                                                                                                                   |
| J/J86 #35        | 40:10                           | 23-25                            | -same as #46 40:10 ratio                                                                                                                                                                          |
|                  | 40:25                           | "                                | -same as #46 40:25 ratio                                                                                                                                                                          |
|                  | 40:50                           | "                                | -same as #46 40:50 ratio                                                                                                                                                                          |
|                  | 40:65                           | "                                | -same as #46 40:65 ratio                                                                                                                                                                          |
|                  | 40:80                           | 23.5                             | -same as #46 40:80 ratio                                                                                                                                                                          |
| J/J86 #22        | 40:10                           | 23-25                            | -same as #46 40:10 ratio                                                                                                                                                                          |
|                  | 40:25                           | "                                | -same as #46 40:25 ratio                                                                                                                                                                          |
|                  | 40:30                           | "                                | -most of material had taken on a moderate plaster-like set except around stirrer-Had to break material up to remove from calorimeter: a mixture of dampish moderately-set lumps                   |
|                  | 40:50                           | "                                | -same as #46 40:50 ratio                                                                                                                                                                          |
|                  | 40:65                           | "                                | -same as #46 40:65 ratio                                                                                                                                                                          |
| J/J86 #41        | 40:80                           | "                                | -same as #46 40:80 ratio                                                                                                                                                                          |
|                  | 40:25                           | 24                               | -same as #46 40:25 ratio                                                                                                                                                                          |
|                  | 40:50                           | 24.7                             | -good working plaster consistency: no excess water - smooth paste                                                                                                                                 |
|                  | 40:65                           | 23.2                             | -same as #46 40:50 ratio                                                                                                                                                                          |
|                  | 40:80                           | 23.5                             | -same as #46 40:65 ratio                                                                                                                                                                          |
| CRF-1            | 40:15                           | 24.5                             | -same as #46 40:25 ratio                                                                                                                                                                          |
|                  | 40:18                           | 24.2                             | -same as #46 40:25 ratio                                                                                                                                                                          |
|                  | 40:25                           | 24.8                             | -same as #22 40:30 ratio-fairly hard to chip out                                                                                                                                                  |
|                  | 40:40                           | 24.1                             | -same as #41 40:50 ratio                                                                                                                                                                          |
|                  | 40:65                           | 23.4                             | -same as #46 40:50 ratio                                                                                                                                                                          |
| CRF-2            | 40:65                           |                                  |                                                                                                                                                                                                   |

TABLE XXXI  
ENGINEERING TESTS OF FIXATED & CURED LIF WASTE SAMPLES RECEIVED FROM LAKEVIEW TGS  
DECEMBER 1985 AND JUNE/JULY 1986

DECEMBER 1985 AND JUNE /JULY 1986

| Sample No                     | Description |         |           |             |                       | Handling Characteristics (Average) |                                        |                                     |                                   | Fixed Material Properties (28-day cure period) |                                   |                                       |                    |                                      |                      |
|-------------------------------|-------------|---------|-----------|-------------|-----------------------|------------------------------------|----------------------------------------|-------------------------------------|-----------------------------------|------------------------------------------------|-----------------------------------|---------------------------------------|--------------------|--------------------------------------|----------------------|
|                               | Date        | Test No | Load (kN) | Sorbent     | Injection Rate (kg/h) | Ca/S Ratio                         | Flue Gas SO <sub>2</sub> Concn. (mg/L) | Blend of Hopper Numbers             | Ratio of Water to LIF Waste (w/w) | Flow Test: Dia of Flow (mm)                    | Bulk Density (kg/m <sup>3</sup> ) | Moisture Content (% Dry Solids Basis) | Shear Strength kPa | Uncertified Compressive Strength kPa | Permeability (cm/s)  |
| D85#4<br>J/J86#14<br>J/J86#19 | Dec 11/85   | 5       | 220       | limestone   | 12.1                  | 3.0                                | 842                                    | 11 (west)                           | 1.0:1                             | 430                                            | 1303                              | 78.1                                  | 174                | 348                                  | 1.4x10 <sup>-4</sup> |
|                               | Jul 4/86    | 5       | 300       | limestone   | 17.8                  | 3.17                               | 1010                                   | 6,8,14,16(East)<br>9,11,17,19(West) | 1.0:1                             | 450                                            | 1319                              | 61.4                                  | 272                | 544                                  | 2.9x10 <sup>-5</sup> |
| J/J86#14<br>J/J86#15          | Jul 9/86    | 11      | 220       | limestone   | 15.2                  | 3.76                               | 756                                    | 6,8,14,16(East)<br>9,11,17,19(West) | 1.2:1                             | 140                                            | 1390                              | 70.0                                  | 253                | 506                                  | 4.4x10 <sup>-5</sup> |
|                               | Jul 10/86   | 3       | 300       | limestone   | 25.0                  | 4.04                               | 825                                    | 6,8,14,16(East)<br>9,11,17,19(West) | 1.2:1                             | 420                                            | 1272                              | 74.9                                  | 147                | 291                                  | 1.4x10 <sup>-4</sup> |
| J/J86#39                      | Jul 14/86   | 4       | 220       | slaked lime | 11.0                  | 3.53                               | 655                                    | 6,8,14,16(East)<br>9,11,17,19(West) | 1.4:1                             | 75                                             | 1367                              | 90.2                                  | 138                | 276                                  | -                    |

There was insufficient sample received from the Combustion Test Facility, Fall, 1986, to conduct engineering tests.

### 5.2.6 Discussion of Tests on LIF Wastes

For the Lakeview TGS samples, the highest solid waste CaO contents were found to be associated with the highest rates of sorbent limestone injection (ie at Ca/S ratios of approximately 4.0). Exothermicity was found by calorimetry to be of the order of  $\Delta H \approx -100$  cal/g whether limestone or slaked lime was injected; likewise bulk exothermicity tests yielded maximum internal temperatures of about 160 to 190°C with either sorbent. The amount of water required to bring 1.0 part of the "as received" waste to a flowable "wet plaster"-like consistency was in the range 1.0 to 1.2 parts for limestone injection wastes and 1.4 parts for slaked lime injection waste. In flow tests, the limestone injection waste exhibited higher flow than the slaked lime injection waste. Bulk densities of the fixated wastes averaged about 1350 kg/m<sup>3</sup> with moisture contents of the limestone injection wastes in the order of 70% by weight (dry solids basis). The moisture content of the fixated slaked lime injection waste was higher, at about 90% by weight (dry solids basis). The shear strength and unconfined compressive strength of the fixated limestone injection wastes were up to double those of the fixated slaked lime injection waste. Permeabilities of the fixated limestone injection waste were in the range  $2.9 \times 10^{-5}$  cm/s to  $1.4 \times 10^{-4}$  cm/s, ie similar to regular fly ash permeabilities.

The selected samples of "as received" and fixated wastes from the Lakeview TGS tests (December, 1985 and June/July, 1986) and from the Combustion Research Facility were subjected to standard MOE leachate extraction tests to assess MOE Hazardous Waste Classification and suitability for landfill disposal. The wastes were found to be non-hazardous (non-leachate toxic) and essentially suitable for landfill use. Moreover, species which form oxy-anions in alkaline solution (eg B, Se and Cr) were found to be lower in aqueous extract concentration when leached from the fixated samples compared to the corresponding original materials. This illustrates the beneficial effects of fixation (primarily done to improve engineering properties) on the leaching process.

### 5.3 Summary and Conclusions

1. It is recommended that care continue to be exercised in handling/disposal of LIF waste because of its confirmed potential for exothermic reaction with water, accompanied by expansion, steaming and dusting.
2. Test show that fixated LIF wastes are non-leachate toxic and essentially suitable for landfill use.
3. Further work is proceeding in the following areas:
  - (i) Laboratory characterization of wastes generated during LIF trials at Lakeview TGS in July-September, 1987. These include wastes derived from injection of (a) limestone and (b) slaked lime.

- (ii) Laboratory evaluation of other LIF wastes produced at the Combustion Research Facility under various operating conditions, eg Ca/S ratio, humidification, alternative sorbents and promoters, etc, as necessary.
  - (iii) Investigation of slaking/conditioning equipment with improved control characteristics compared with the dustless unloaders currently in use, eg at Lakeview TGS.
4. Plans are being made to test practicability of disposal on a larger scale. For this purpose, test plots will be constructed and filled with conditioned LIF waste/water mixes. Field leaching behaviour will be studied.

#### 6.0 OVERVIEW OF FGD WASTE STUDY

From a review of FGD literature, and from information provided by existing FGD facilities, typical physical and chemical characteristics of potential solid FGD wastes are described for four processes being considered by Ontario Hydro for installation at coal-fired thermal generating stations. The candidate processes are: Limestone Slurry Scrubber, Dual Alkali, Limestone Spray Dryer, and Limestone Injection.

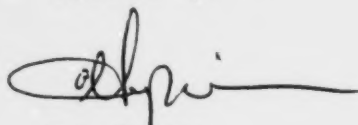
With Limestone Slurry scrubbing in particular, there may be need for significant blowdown of process liquor as waste water. Unless the water loop can be effectively "closed" this could pose problems in relation to permissible discharge limits. Alternative technologies for closing the loop, notably including mechanical evaporation, have been considered. With proper design and management, the impact of waste disposal site leachate formation and migration can be minimized for most wet limestone slurry process variations.

Likewise, disposal of solid wastes from the other three processes must be engineered so as to minimize environmental impact.

Dual alkali FGD operation is characterized by minimal wastewater discharge, so as to conserve the relatively expensive sodium-based reagent. Lime spray drying and limestone injection processes are essentially free from wastewater discharge.

Limestone injection waste disposal has been the least developed of the four candidate processes being considered. LIF waste disposal is at present under vigorous investigation by Ontario Hydro.

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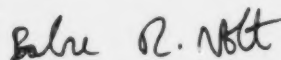
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Chemical Research Department

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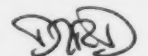


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## REFERENCES

1. A. Golomb, "Limestone Scrubber FGD Wastewaters/Leachates: A Literature Review". CEA Report No. 435G504, July, 1986.
2. A. Golomb, Research Division Report No. C81-107-H.
3. "Chemical/Physical Stability of Flue Gas Cleaning Wastes", EPRI Report No. FP-671. Project 786-2. (Final Report). January, 1979. Prepared by Radian Corporation, Austin, Texas.
4. "FGD By-Product Disposal Manual," Third Edition. EPRI Report No. CS-2801. Project 1685-4. (Final Report). January, 1983. Prepared by Michael Baker Jr., Inc., Beaver, Pennsylvania.
5. "Technical/Economic Assessment of Closed Process Water Loop Systems for Flue Gas Desulphurization", Environment Canada, Environmental Protection Service. March, 1985. Prepared by CH2M Hill, Calgary, Alberta.
6. "Flue Gas Cleaning Wastes Disposal and Utilization" Noyes Data Corporation, Park Ridge, N.J., USA, 1981.
7. "Design and Operation Checklists for Zero Discharge Power Plant Water Systems." EPRI Report No. CS-4045, prepared by Water Management Associates, June, 1985.
8. "SO<sub>2</sub> Abatement for Coal-Fired Boilers in Japan." United States EPA Report No. EPA/600/7-83-028, prepared by Jumpei Ando, Chuo University, Tokyo, Japan, May, 1983.
9. Colley, D., Stewart, D., Wadlington, M., and Stewart, D., "FGD System and Water Balance Improvements at Texas Utilities Generating Company's Martin Lake Station". Paper presented at Symposium on Advances in Fossil Power Plant Water Management, February 12-14, 1986, Orlando, Florida.
10. "Environment Canada. Environmental Codes of Practice for Steam Electric Power Generation - Design Phase." Report EPS 1/PG/1. March, 1985.
11. "An Evaluation of Flue Gas Desulphurization Wastewater Treatment by Mechanical Evaporation". Unpublished report by Canviro Consultants Ltd., prepared for Environment Canada, March 1985.
12. Tang, T.L.D., Chu, T-Y.J. and Boroughs, R.D., "Application of Membrane Technology to Power Generation Wastes," United States EPA Report No. EPA-600/7-80-063. March, 1980.
13. Golomb, A., "Reverse Osmosis Application Studies," Ontario Hydro Research Division Report No. 81-497-K.

14. Golomb, A. "Reverse Osmosis Treatment of Coal-Fired Power Plant Wastewater." Paper presented at 7th Symposium on Wastewater Treatment, Montreal, P.Q., Canada, November 20-21, 1984.
15. Sourirajan, S. (Editor). "Reverse Osmosis and Synthetic Membranes." Published by National Research Council Canada, 1977.
16. "Study on Sulphur and Nitrogen Oxide Emissions Control Technology". CEA Report No. 202G316. Prepared by Montreal Engineering Co. Ltd. August, 1983. (2 volumes).
17. C. Wedig, Stone & Webster Inc., Boston, Massachusetts, USA. Personal Communication, 19 July, 1986.
18. "Landfill Disposal of Limestone Dual Alkali Flue Gas Desulphurization Waste". EPRI Report No. CS-2559. Prepared by A.D. Little, Inc., Cambridge, Massachusetts, USA. September, 1982.
19. Klimek, A.P., Eklund, A.G., Gaynor, W.D. and Golden, D.M., "Design of Waste Management Systems for Calcium Spray Dryer FGD Technology," Paper #10F, presented at the 10th Symposium on Flue Gas Desulphurization, November 18-21, 1986, Atlanta, Georgia, USA.
20. "Ontario Hydro: Flue Gas Desulphurization Program - Environmental Assessment." (Draft). April 22, 1987.
21. Donnelly, J.R., Ellis, R.P., and Webster, W.C. "Dry Flue Gas Desulphurization End-Product Disposal - Riverside Demonstration Facility Experience". Paper presented at EPA/EPRI Symposium on FGD, Hollywood, Florida USA. May, 1982. (EPRI CS-2897 - vol. 2).
22. "Characteristics of Waste Products from Dry Scrubbing Systems". EPRI Report No. CS-2766. Prepared by Radian Corporation December, 1982.
23. Donnelly, W.C. and Webster, "Synthetic Gravel from Dry Flue Gas Desulphurization End-Products." Paper presented at the 6th International Ash Utilization Symposium, Reno, Nevada, March, 1982.
24. "Field Evaluation of a Utility Spray Dryer System". EPRI Report No. CS-3954, Prepared for EPA/EPRI by Radian Corporation, Austin, Texas. May, 1985.
25. P.S. Farber, "Emissions Control Through Dry Scrubbing", Environmental Progress, 1986, 5, (3), 178.
26. A. Golomb, Research Division Report No. 85-340-K.
27. A. Golomb, Research Division Report No. 87-146-K.

28. Dahlin, R.S., Lishawa, C.L., Nolan, P.S., and Kaplan, N., "Disposal, Recycle, and Utilization of Modified Fly Ash from Hydrated Lime Injection into Coal-Fired Utility Boilers." Paper presented at the 80th Annual Meeting of APCA, New York, N.Y., June 21-26, 1987.
29. "Technical Options for the Disposal of Circulating Fluidized Bed Combustion Solid Wastes". Phase I Report by Dearborn Environmental Consulting Services Ltd. Prepared for Environment Canada. March 31, 1987.
30. G.M. Matsugu, Wallace and Tiernan, Scarborough, Ontario, Canada. Personal Communication, March 27, 1985.
31. C.A. Holley, Ferro-Tech, Wyandotte, Michigan, USA. Personal Communication, May 16, 1985.
32. "MOE Leachate Extraction Procedure". Memo from D. Harrison to D.K.A. Gillies. April 30, 1984.
33. "Government of Ontario. Regulation 309. Revised Regulations of Ontario, 1980, as Amended to O. Reg. 322/85, under Environmental Protection Act (General-Waste Management). November, 1985.

APPENDIX A

FLOW SCHEMATICS OF PRINCIPAL PROCESS VARIATIONS OF LIMESTONE

SLURRY FGD SCRUBBING

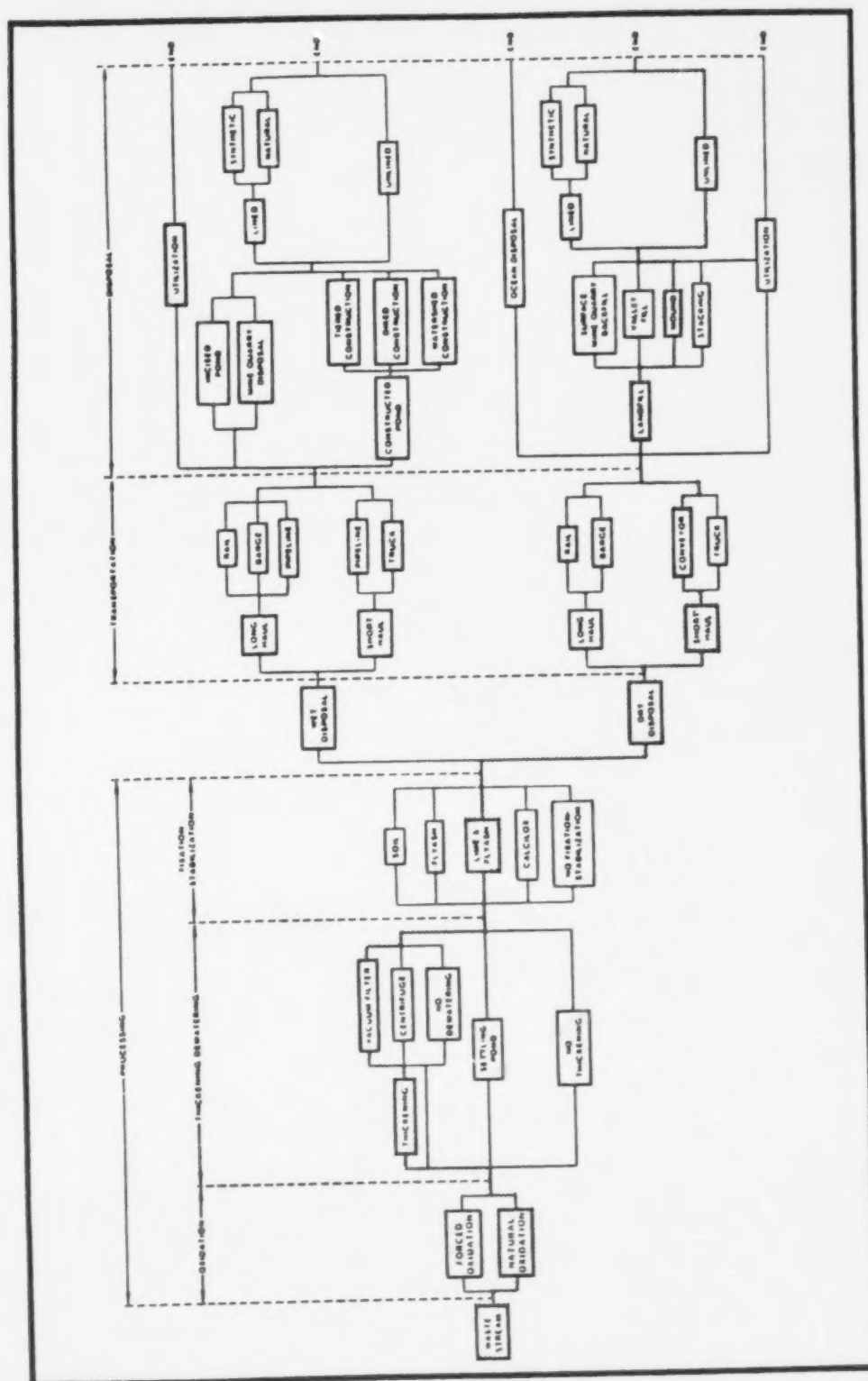


Figure A-1: Dry Disposal of Sludge After Dewatering and Blending with Lime and Flyash. /4/

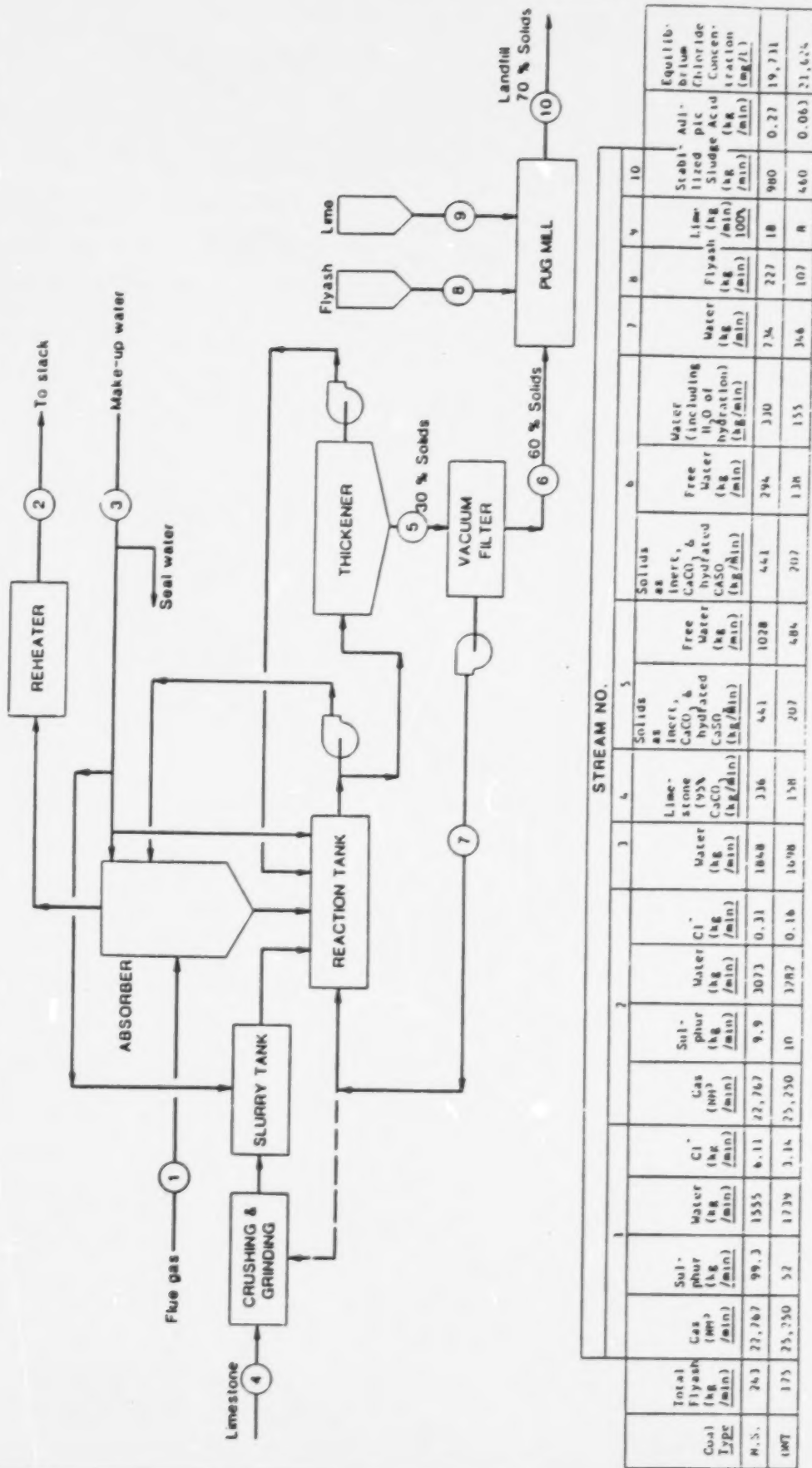
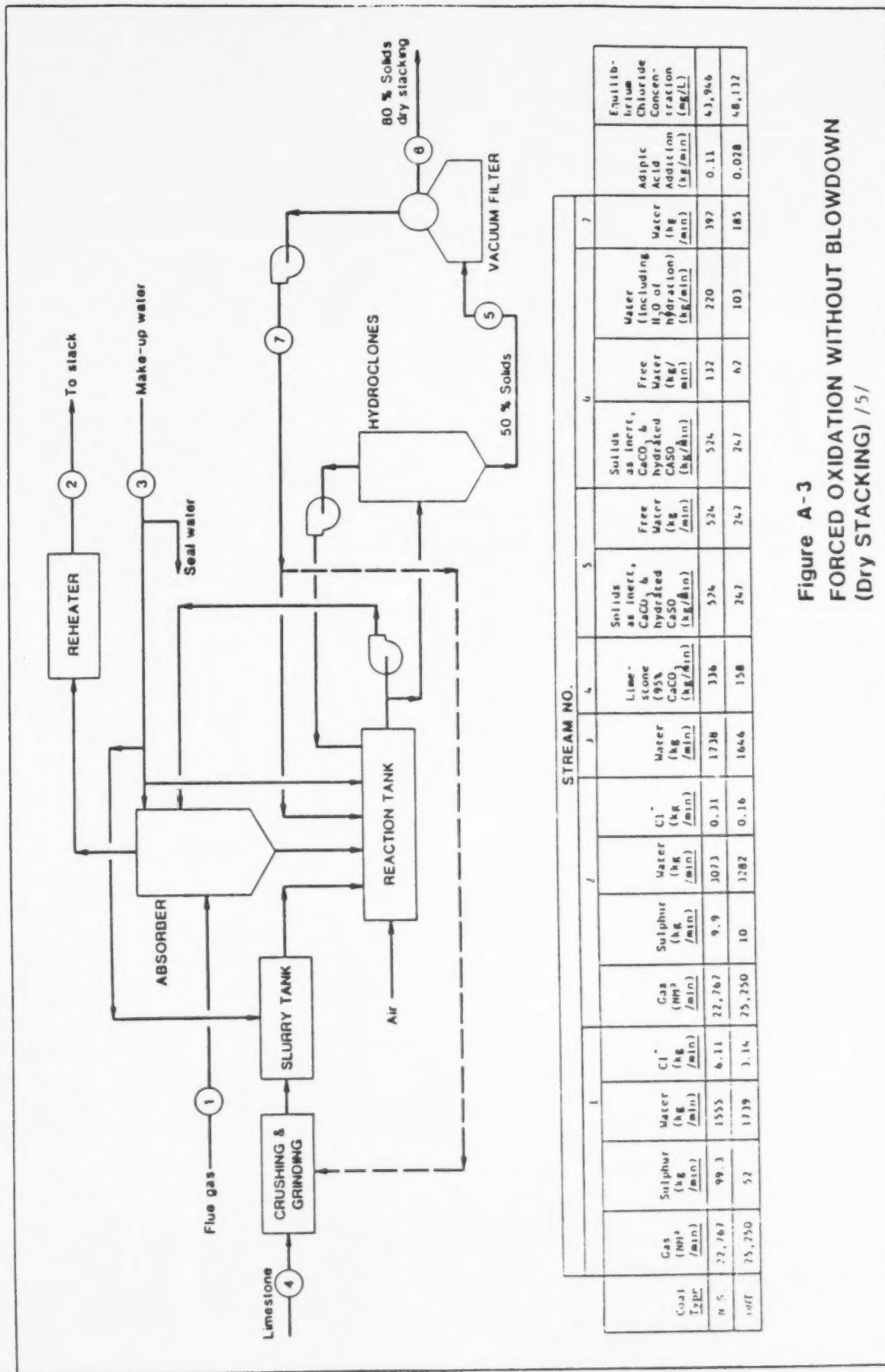
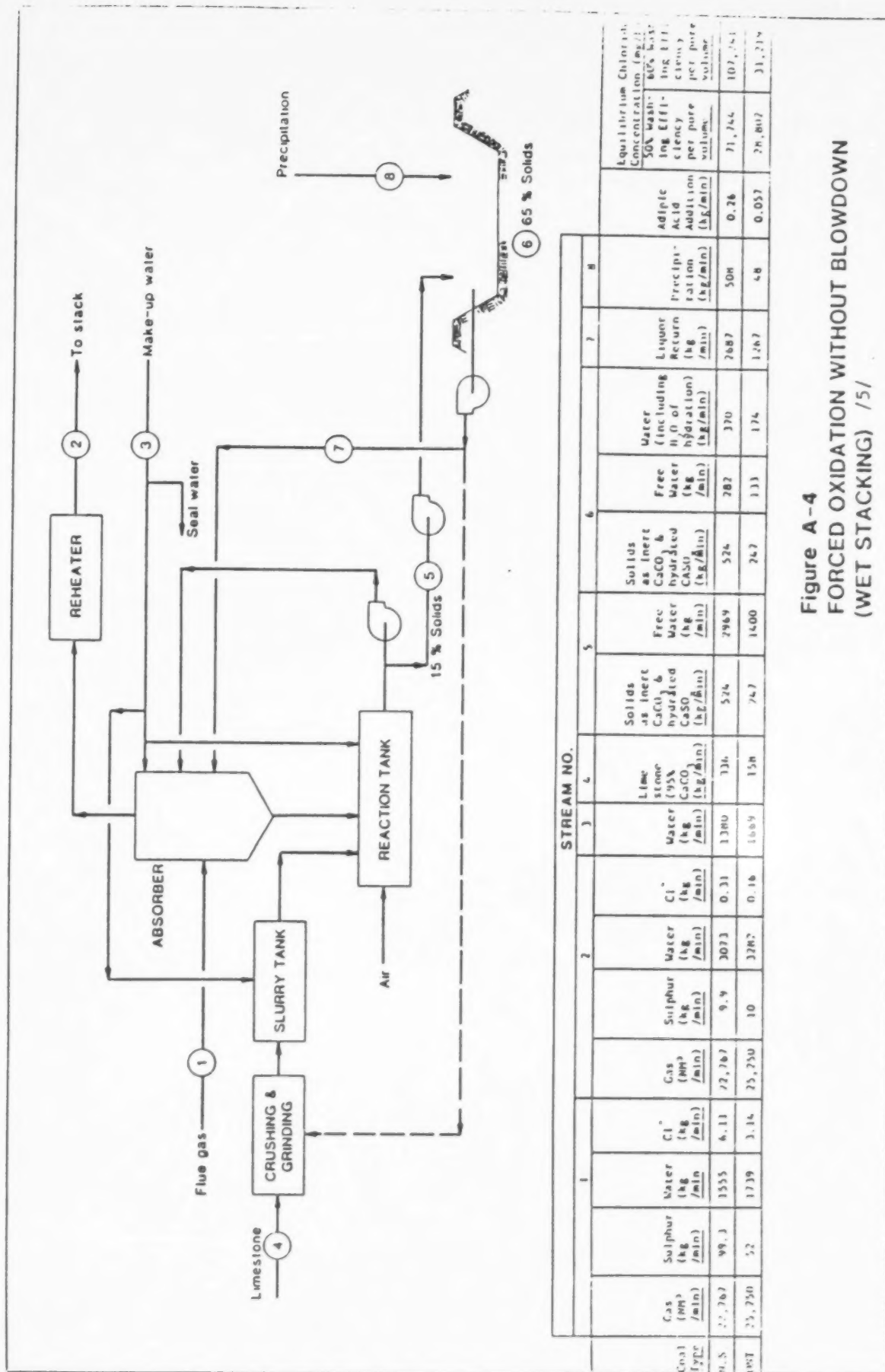
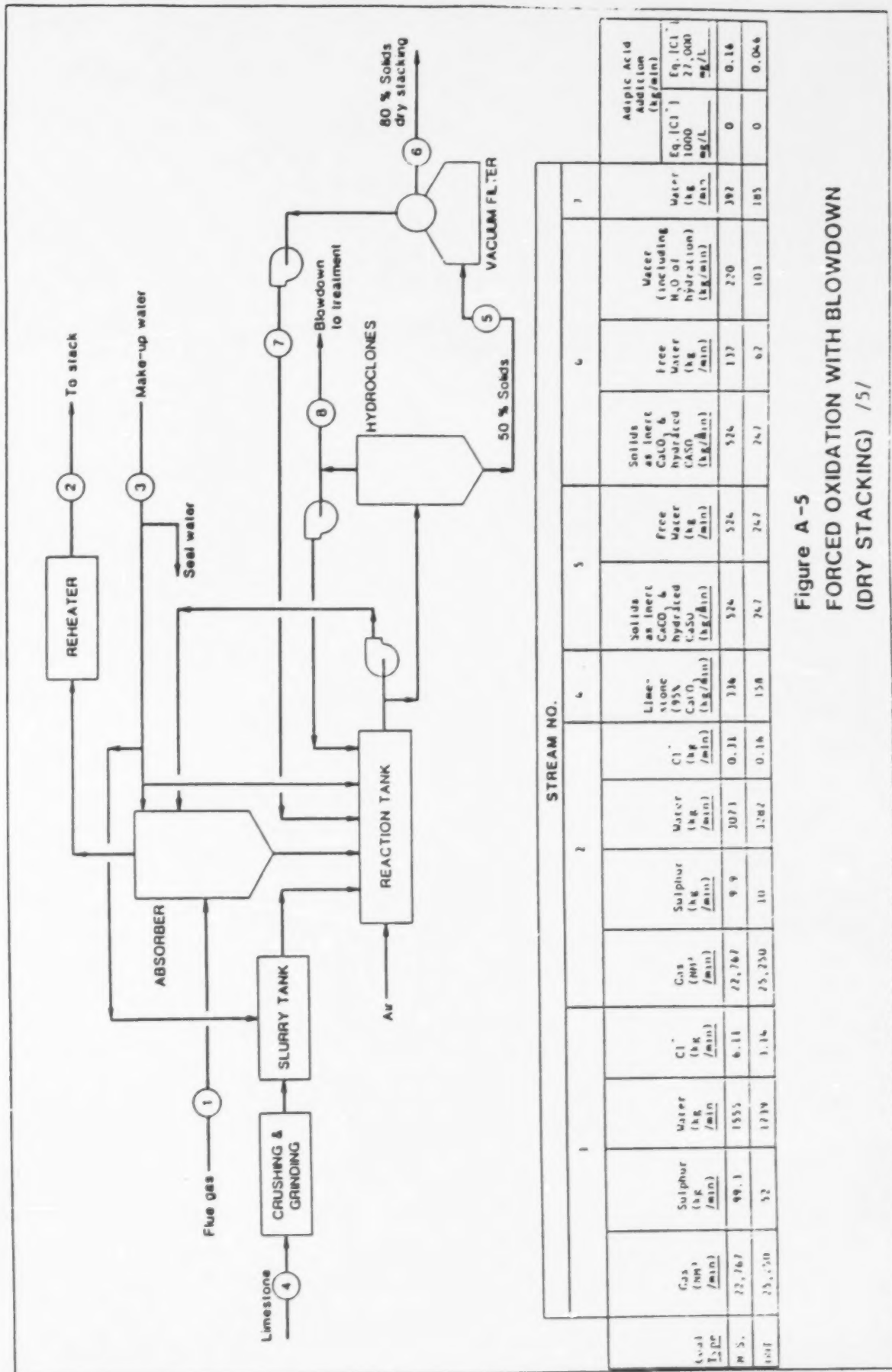


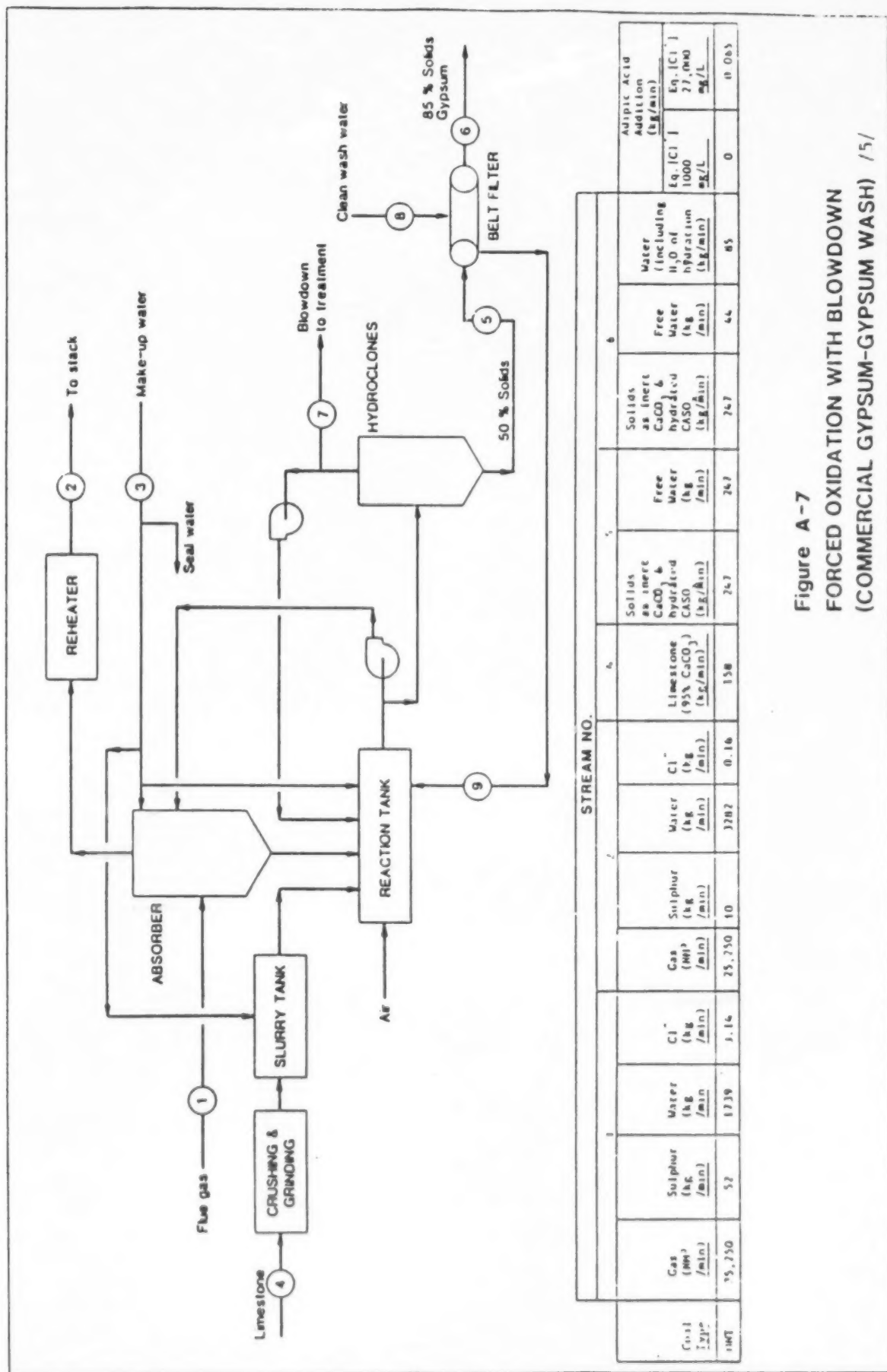
Figure A-2  
NATURAL OXIDATION WITH  
SLUDGE STABILIZATION /5/











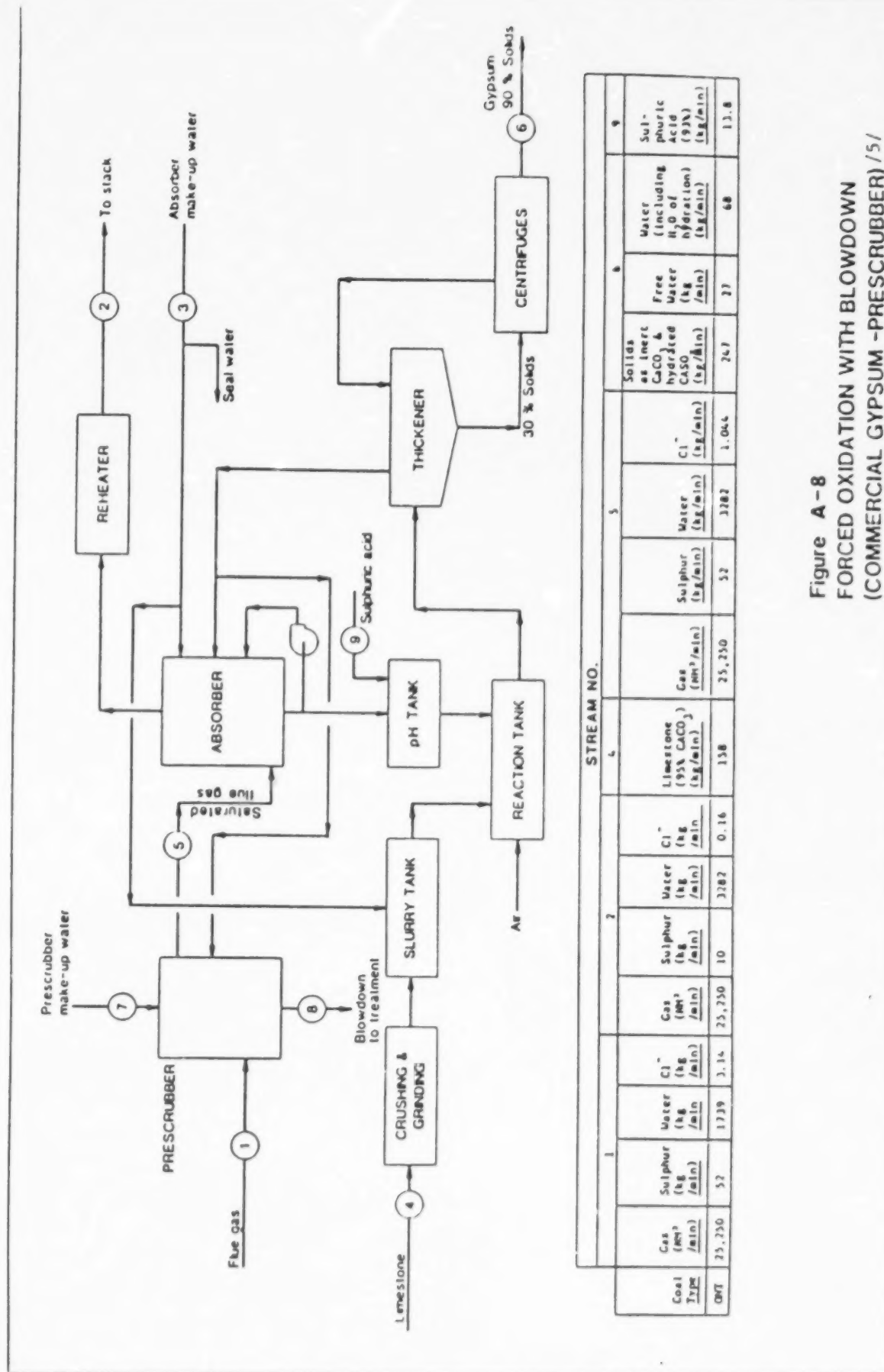


Figure A-8  
FORCED OXIDATION WITH BLOWDOWN  
(COMMERCIAL GYPSUM - PRESCRUBBER) / 5/